



The Operational Simplified Surface Energy Balance (SSEBop) Approach for ET Estimation

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USGS EROS/NC CSC

Workshop on “Estimating ET using RS and EB Methods”, Helena Montana
WebEx Presentation

May 29, 2015

Team and Contributors

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- Robert Flynn

- University of Montana:

- Jared Oyler



Outline

- Summary
- Background and justification
- ET Products (drought monitoring and water budget analysis)
 - MODIS (operational)
 - Landsat based ET
- Conclusions

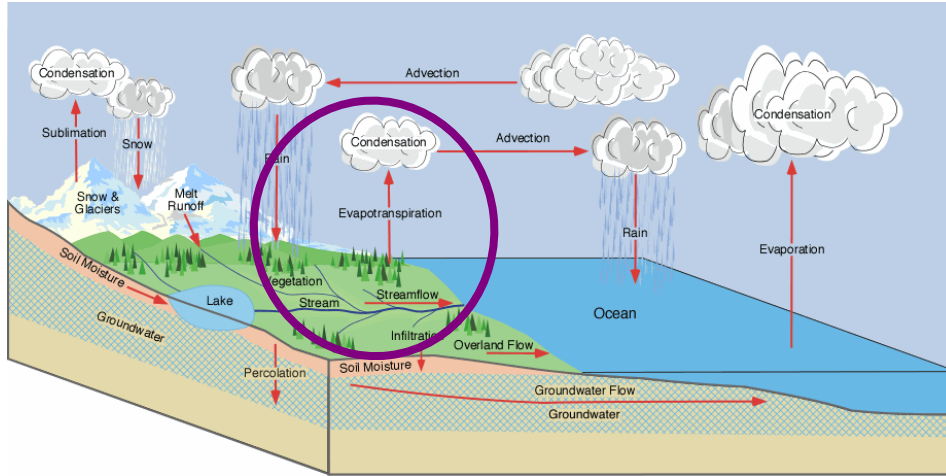


Summary

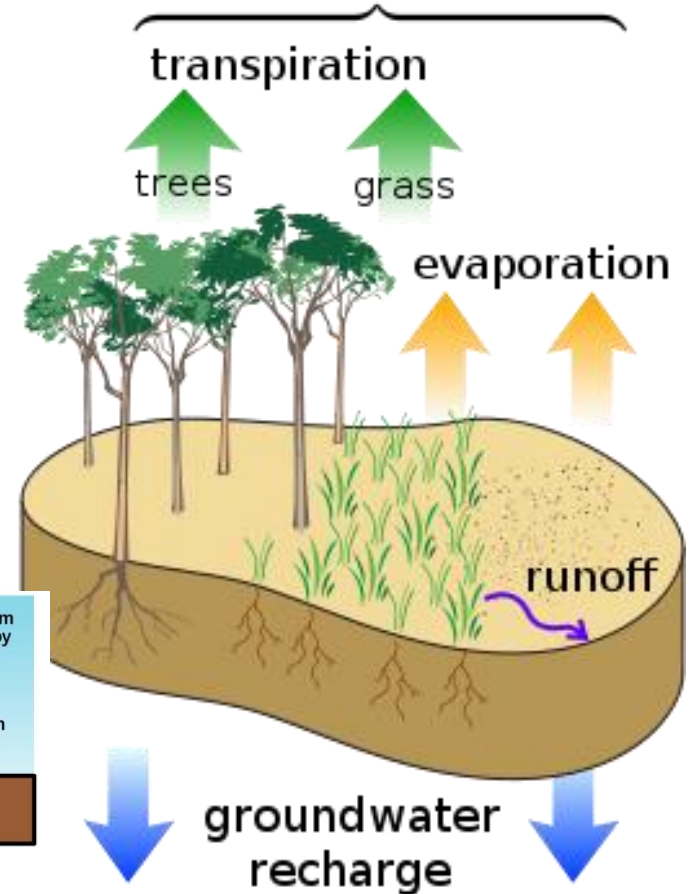
- Satellite-based ET is being estimated operationally using Land Surface Temperature (LST) as the main driver.
- Applications for drought monitoring is reliable as is.
- Application for water budget analysis will require careful attention to potential region-specific bias



Hydrologic cycle

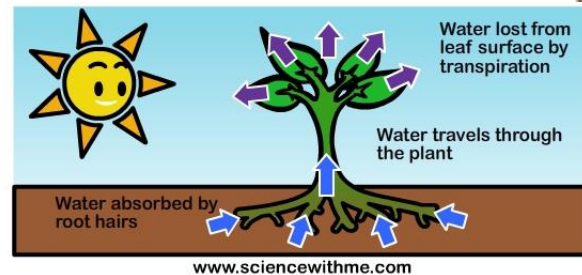


evapotranspiration =
transpiration + evaporation



Challenge with ET:

- 1) Gaseous state
- 2) Invisible
- 3) Only indirect measurement



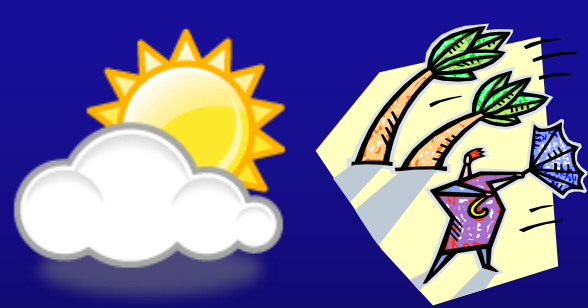
Why ET?

- It is a **RESPONSE** variable as opposed to precipitation (driver)
- It reflects the integrated effects of Energy/Aerodynamics, Soil Moisture, Vegetation and Environmental Stress

- **Potential**

Energy

Wind/RH



- Limitations**

Moisture

Vegetation

Env. Stress

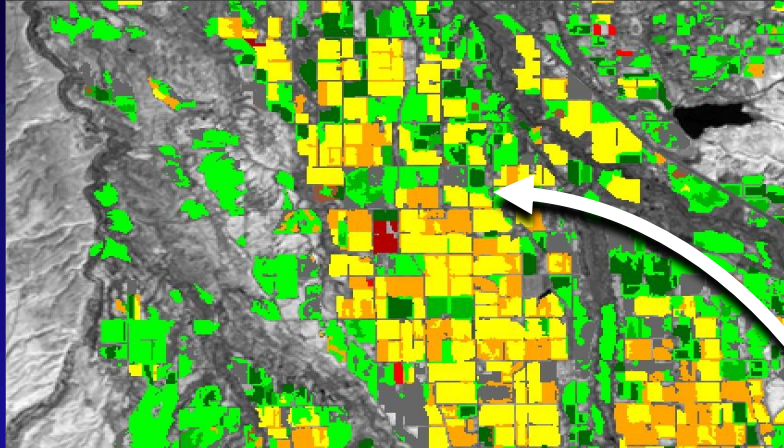


Purpose: EROS WaterSMART/Water Census

- **Develop/improve** ET model for crop consumptive use estimation
- **Apply** ET model on regional and national scales for water use and water availability quantification.
- And drought monitoring on a global scale for USAID.



Who, how much, when?



D. Eckhardt

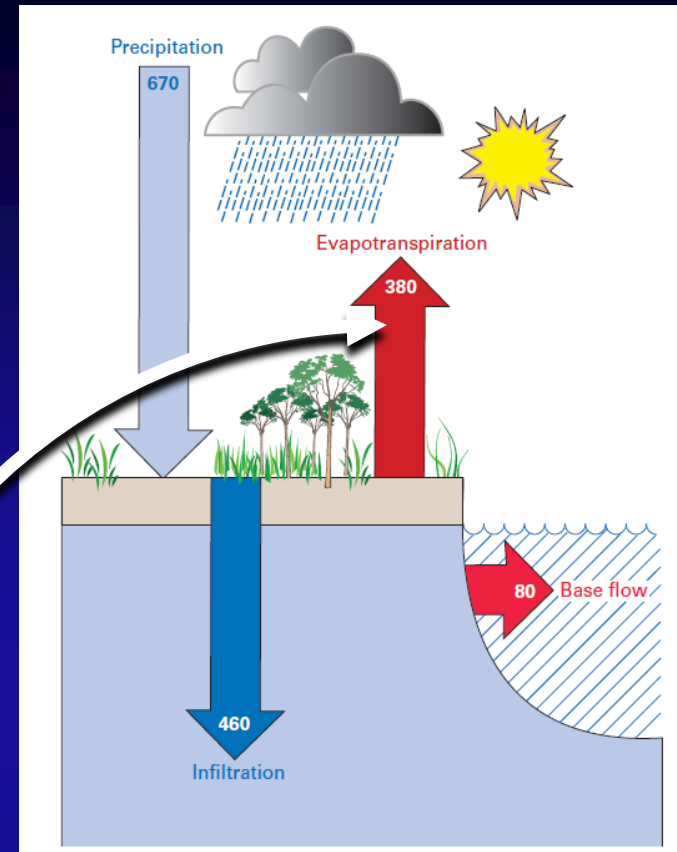
Water Use Effort:

For irrigation water use to estimate consumptive use.

12 digit HUC
Watershed



ET



Water Budget Effort:

Total ET as a component of the water budget.

Temporal Scale: Monthly, weekly, daily ??

Trends for how many years back ??



Role of Remote Sensing

- Land Surface Temperature (LST) from thermal imagery
 - Landsat (~100m)
 - MODIS (1km)
 - AVHRR (1km)
 - GOES (10km)
- Precipitation Estimate
 - NOAA NEXRAD (5km)
 - METEOSAT RFE (10km)
 - NASA TRMM (25 km), etc



Two Principles for ET Estimation...

- **Water Balance**
 - driven by **precipitation** accounting
- **Energy Balance**
 - driven by **Land Surface Temperature (LST)**



Several Approaches...

- Soil Moisture Modeling
 - Land Surface Models such as Noah, SWAT, VIC...
- Vegetation Index based
 - NDVI/LAI-based: MOD16, P-M, P-T
- Mixed Approach
 - NDVI-LST (Trapezoid, Triangle...)
- Surface Energy Balance
 - SEBAL/METRIC, SEBS, Two-Source, ALEXI, S-SEBI, **SSEBop**...



Which model(s) to use...

**All models are wrong but
some are useful**

(George E. P. Box, 1976)



Water Balance Limitations

- **Requires:**
 - rainfall data
 - characterization of vegetation water-use patterns
 - information on soils
- **Difficult to estimate:**
 - irrigation applications
 - sub-surface extraction by deep rooted plants and wetland ET
 - The impact of pest and diseases on ET



Water Balance Limitations

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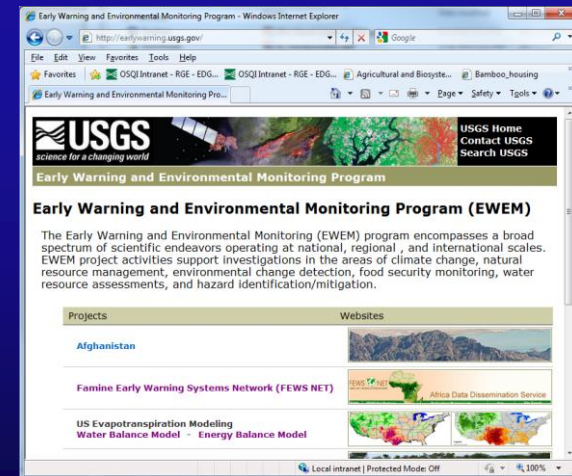


Energy Balance Approach for ET

http://earlywarning.usgs.gov/usewem/eta_energy.php

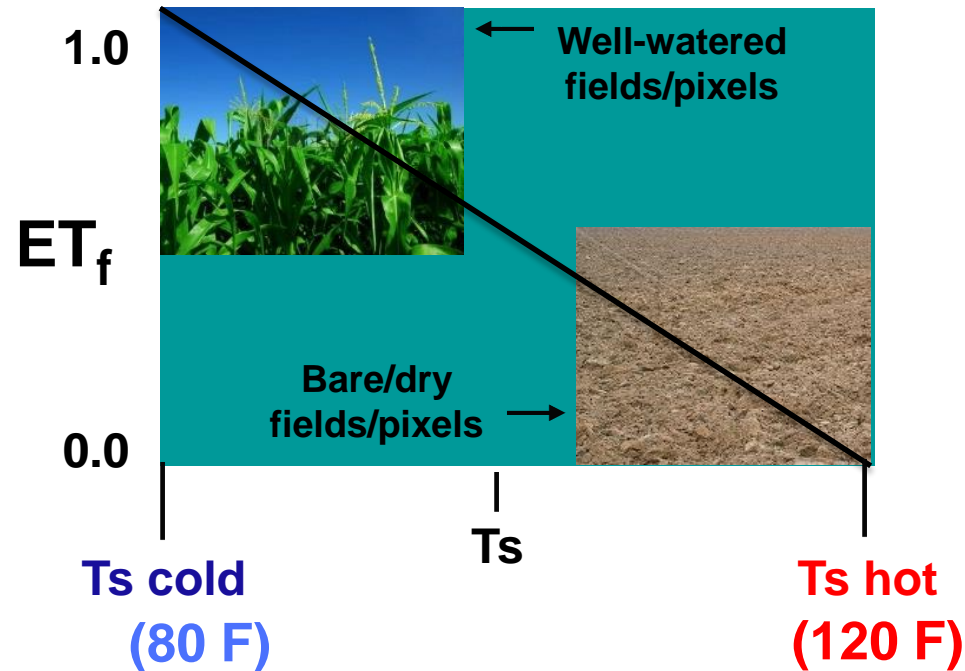
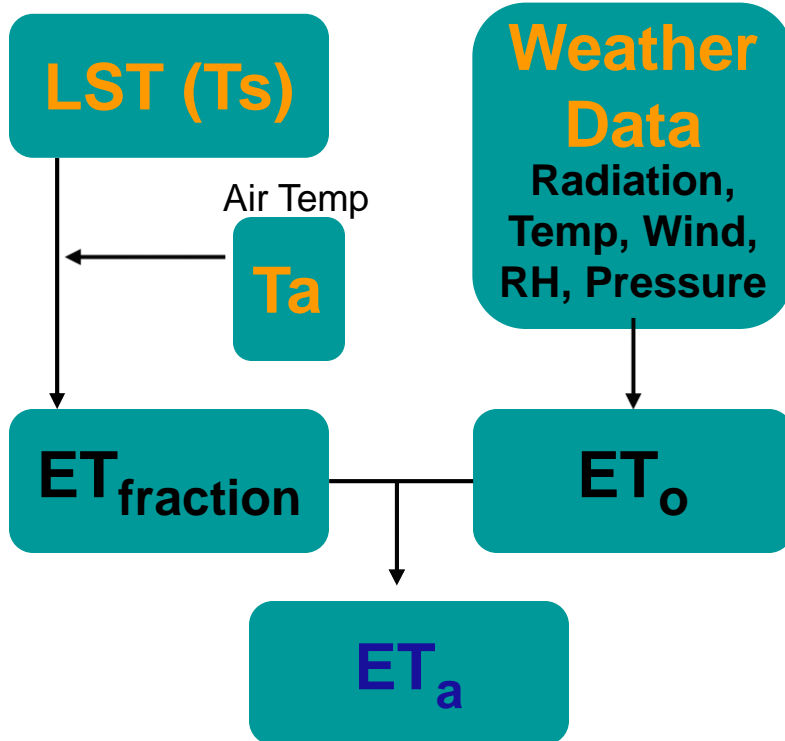
USGS **WaterSMART** and **FEWS NET** use the **SSEBop** (Operational Simplified Surface Energy Balance) approach for:

- 1) Water Use and Availability Assessment
- 2) Drought Monitoring & Early Warning



Operational Simplified Surface Energy Balance (SSEBop) Modeling Approach

Land Surface Temp



Adapted the “hot” and “cold” pixel concept from SEBAL (Bastiaanssen et al., 1998) and METRIC (Allen et al., 2007) to calculate ET fraction and combine it with ETo.

SSEB: Senay, et al., 2007 sensors; 2011 AWM; **SSEBop:** 2013 JAWRA.



Using surface energy balance principles

ET as a Residual:

$$R_n = LE + H + G$$

$$H = \frac{\rho C_p (T_s - T_a)}{r_a}$$

$$LE = R_n - H$$

$G \approx 0$ for daily estimate

SSEBop: Pre-defined dT

Varies in space and season
but constant from year-to-year
under clear-sky conditions

RS-ET possible under “clear sky”
conditions only.

ET Direct, SSEBop:

$$\lambda ET = ET = ET_f * ET_o$$

$$ET = \frac{T_h - T_s}{dT} * ET_o$$



$$dT = \frac{R_n r_a}{\rho C_p}$$

$$ET = \frac{\rho C_p (T_h - T_s)}{R_n r_a} * ET_o$$



Pre-defined Boundary Conditions are KEY!



Jul 4, 2012

Transect:

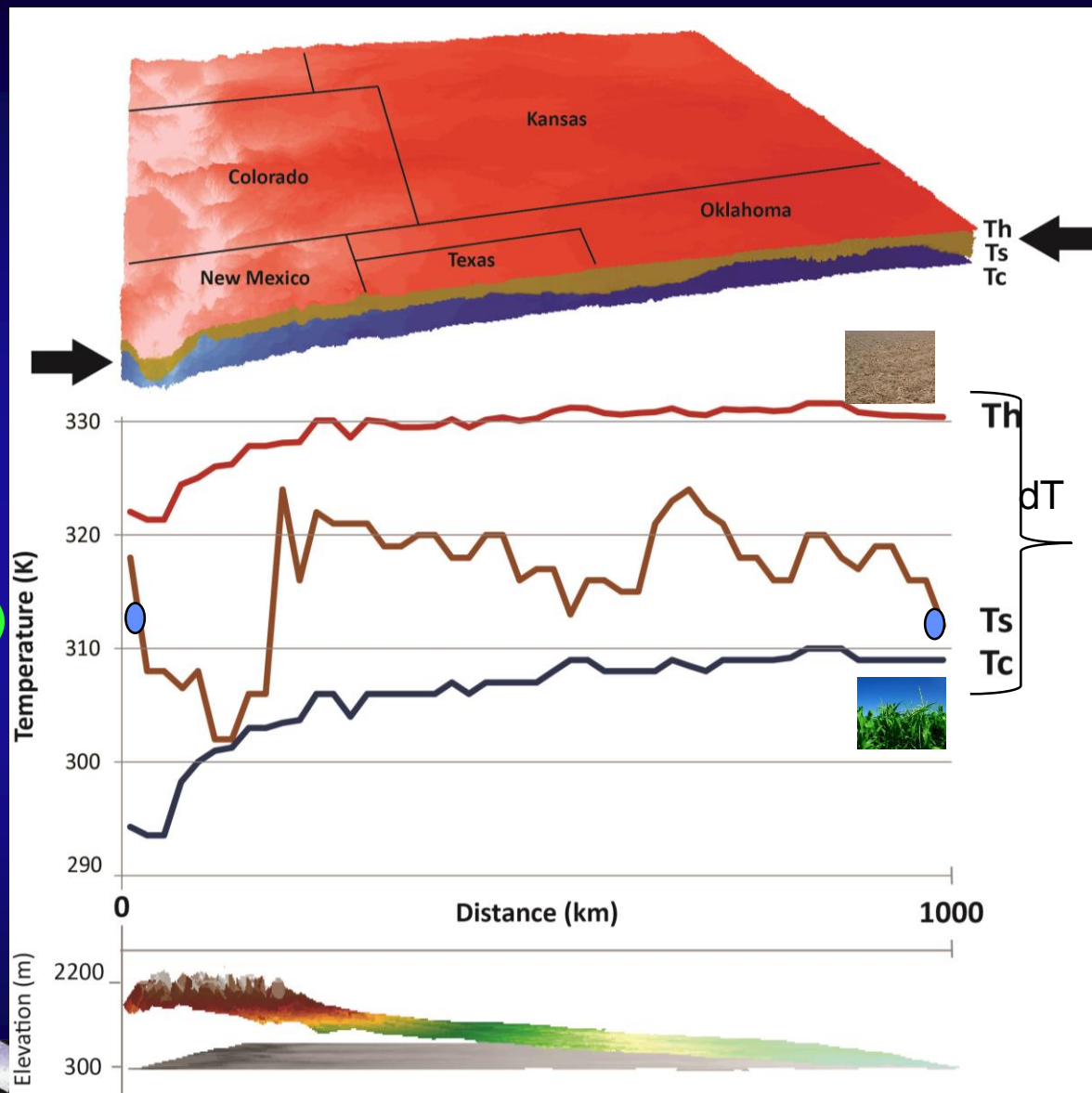
T_s = MODIS LST

T_c = Cold boundary (c. T_{a_max})

T_h = $T_c + dT$

310 k = 99 F

330 k = 135 F



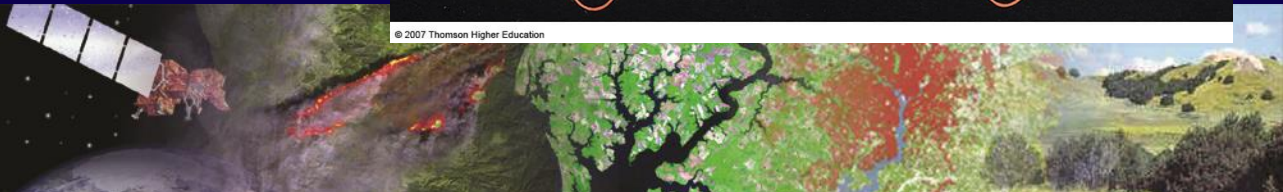
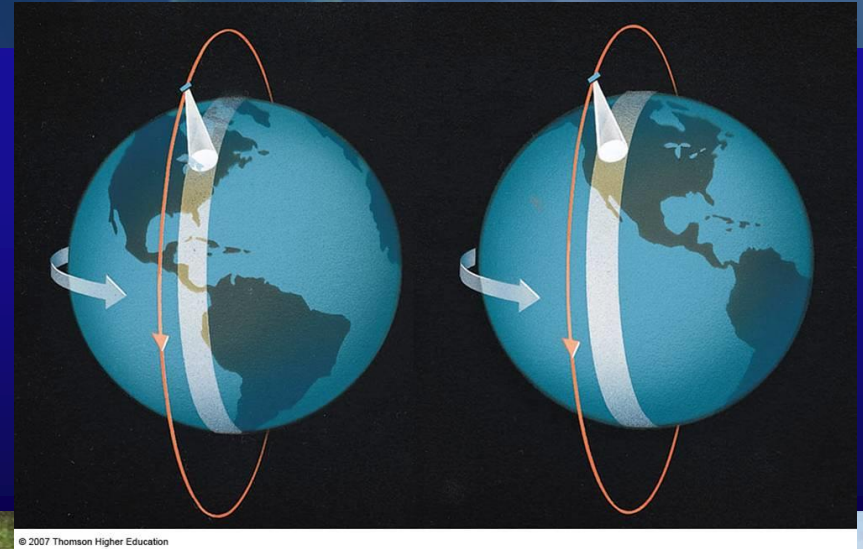
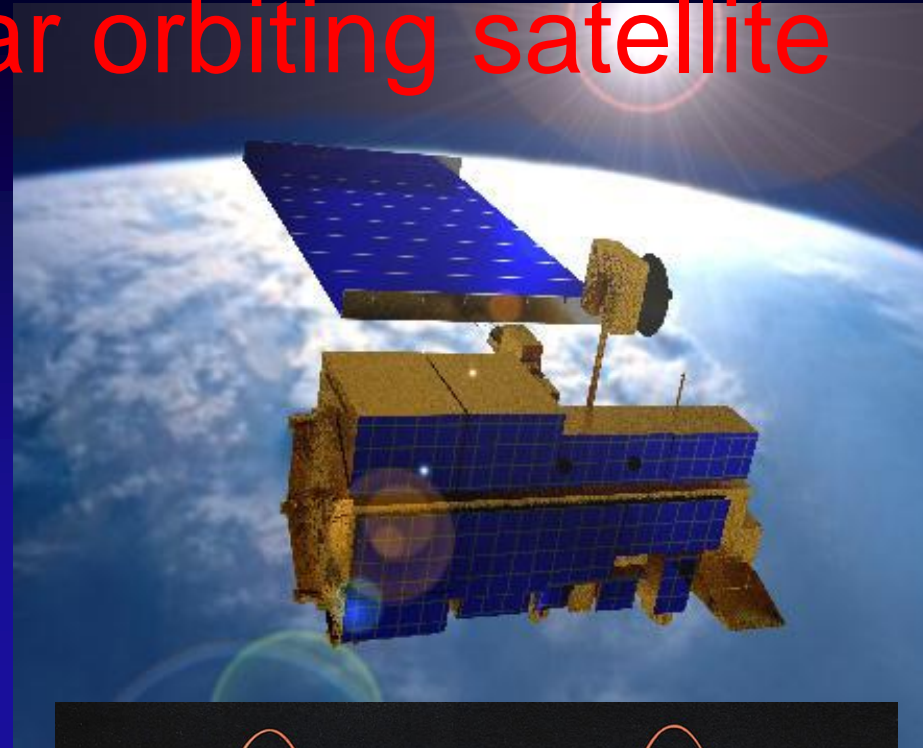
Source of Input Data...

- Land Surface Temperature (LST) from thermal imagery
 - Current implementation with SSEBop
 - Landsat (~100m)
 - MODIS (1km)
- Air Temp: Daymet, TopoWx, PRISM, Worldclim
- ETo: model assimilated global weather datasets such as GDAS and NLDAS or station-based P-M ETo fields.

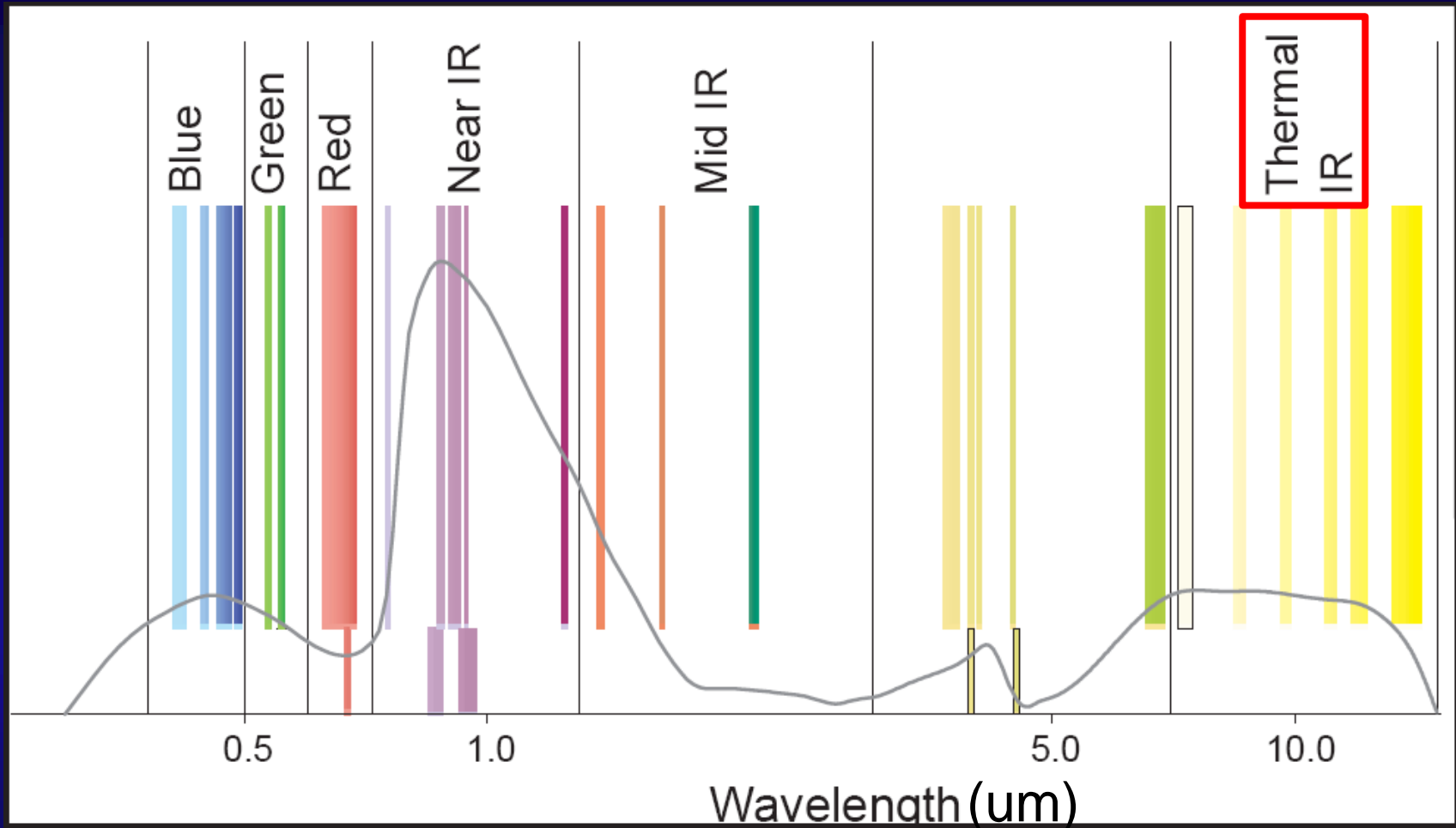


Images from a polar orbiting satellite

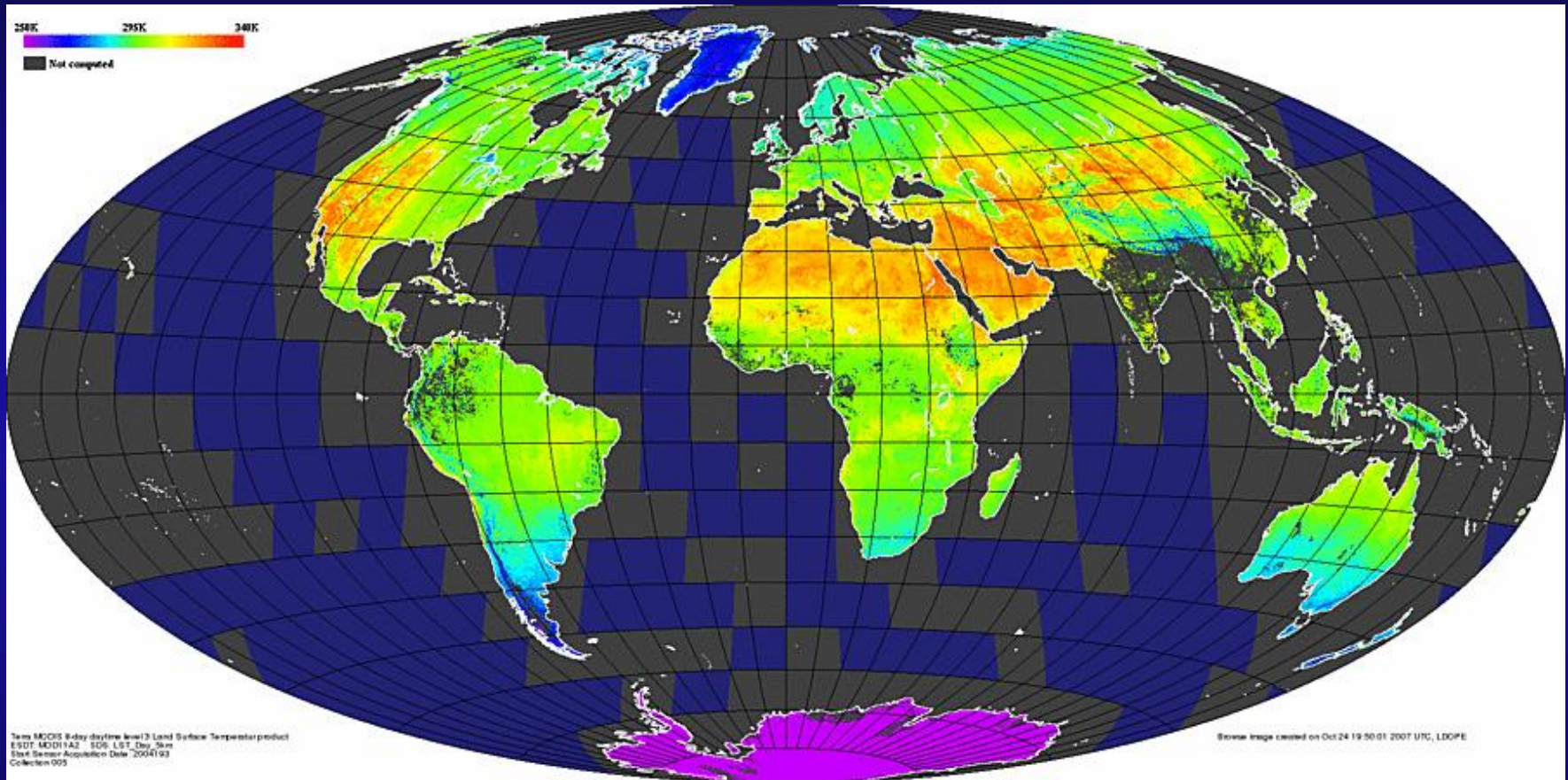
Satellite: Terra (EOS AM-1)
Sensors: MODIS, and 4 others
Altitude: 725 km
Repeat: daily at 10:30 am
Period: 98.8 minutes



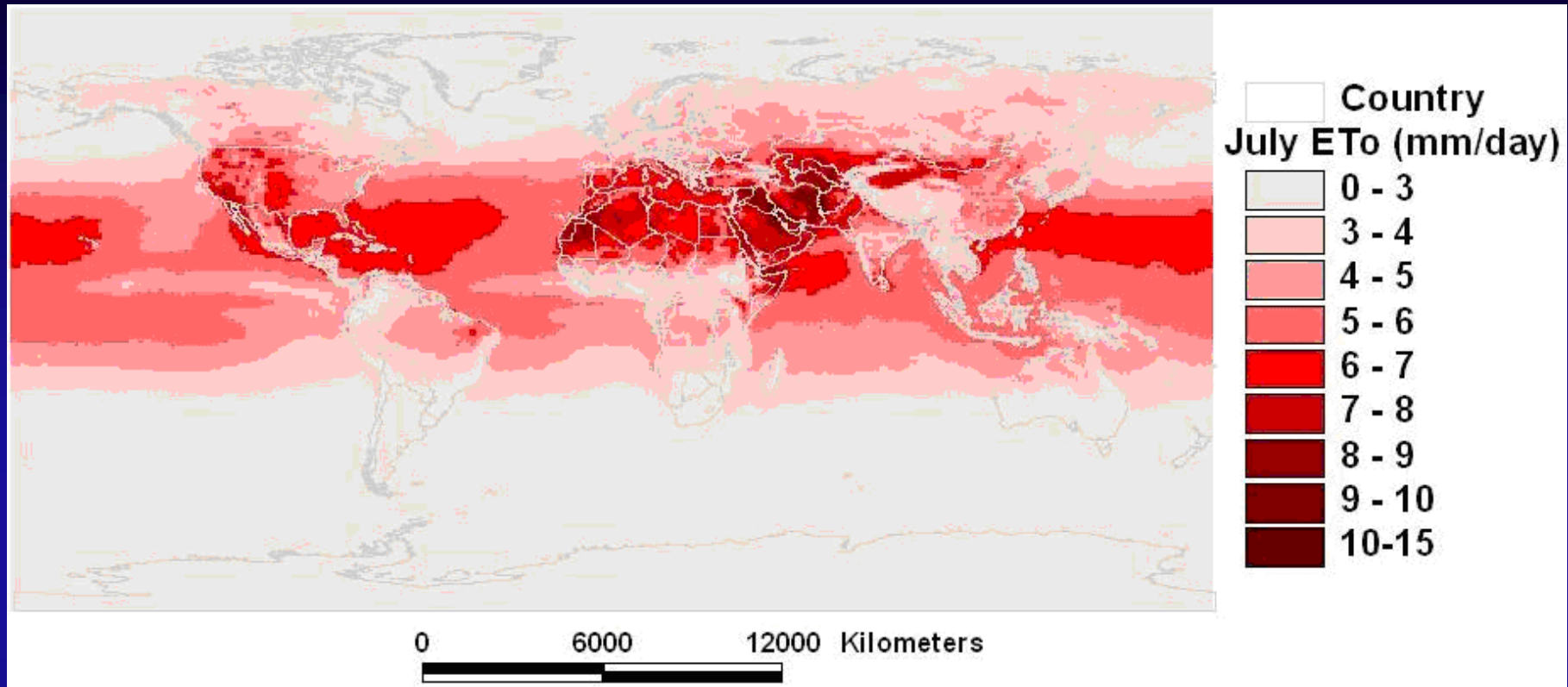
MODIS Spectral Bands (36)



MODIS 8-day Land Surface Temperature (1-km spatial resolution)



Daily Global GDAS ETo for July 2004



$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)}$$

6-hr weather forecast data from NOAA:
Radiation, temp, wind, RH and pressure
to solve the standardized P-M Equation

<http://earlywarning.usgs.gov/Global/dwnglobalpet.php>



Topoclimatic Datasets

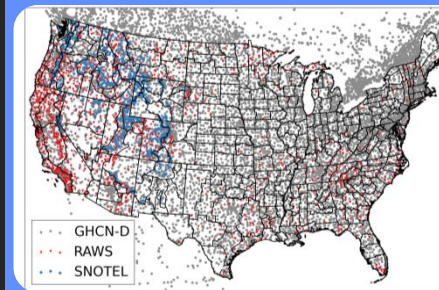


Interpolated Topoclimatic Datasets:

Use point-source weather station data and a DEM to incorporate the effects of topoclimatic factors and statistically interpolate climate variables to a regular grid.

- PRISM 
- DAYMET 
- Maurer et al. and Livneh et al.

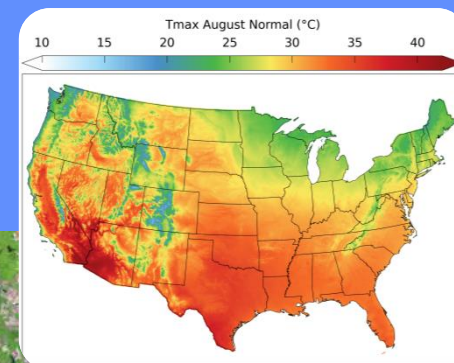
Weather Stations



DEM and DEM-Derived Variables



Interpolated Topoclimatic Dataset

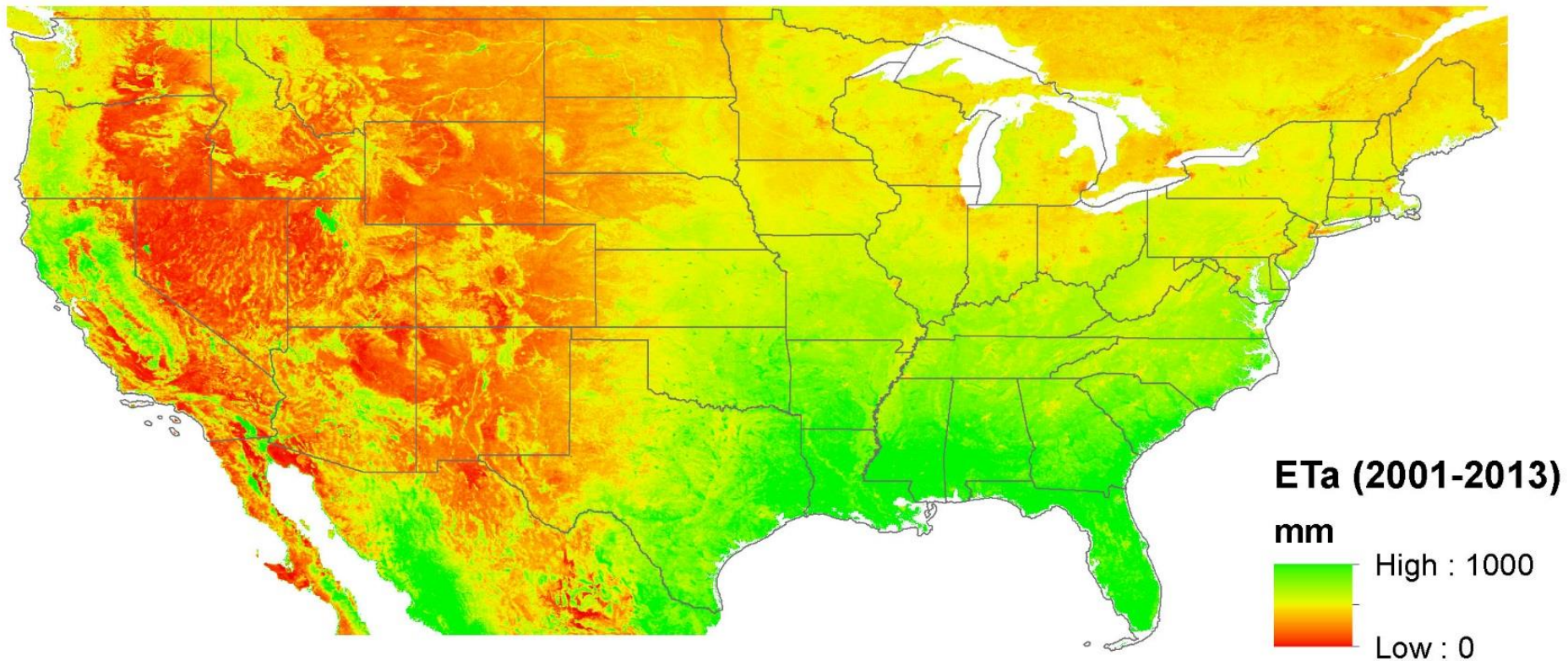


Model Performance Evaluation...

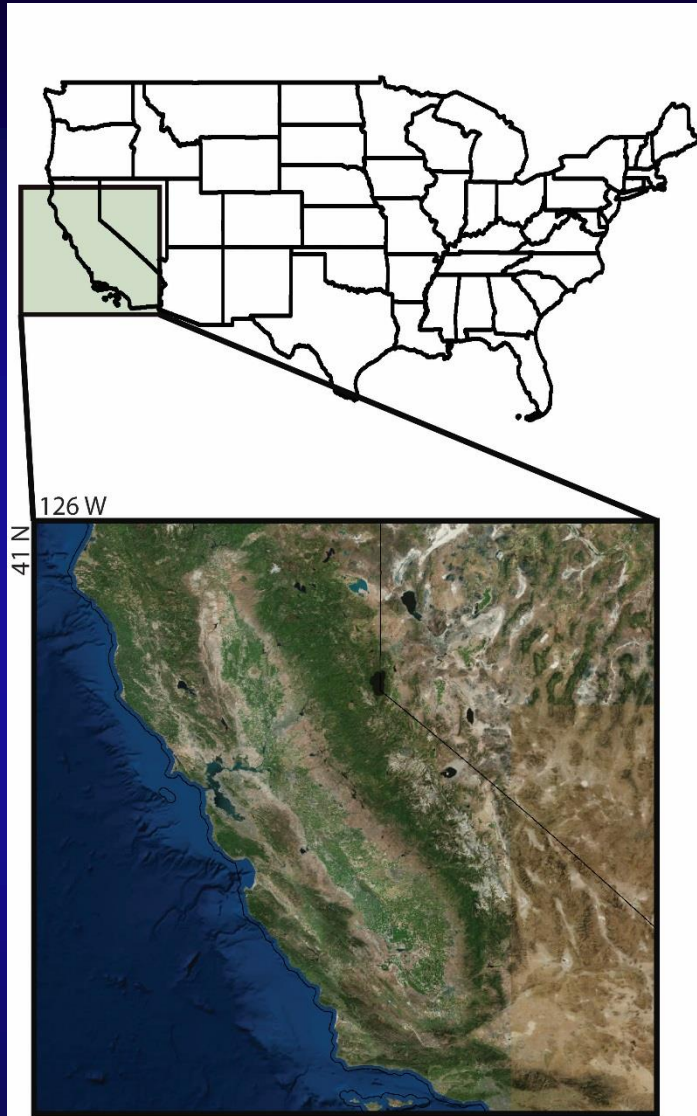
- Visual, qualitative spatial patterns
- EC Flux Tower
- Water Balance



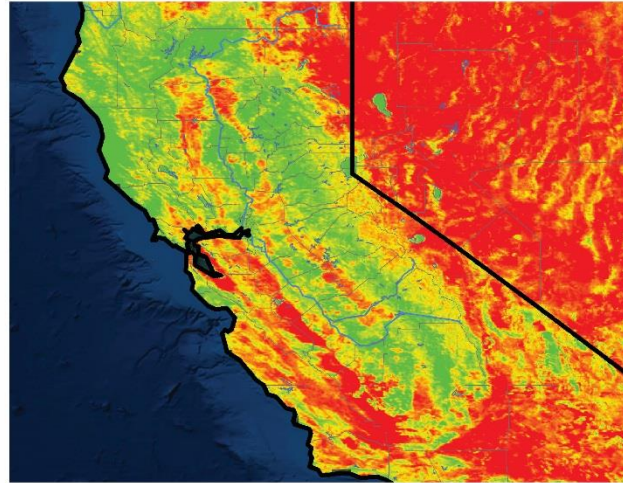
Annual ETa Distribution (mm) (median of 2001-2013, SSEBop)



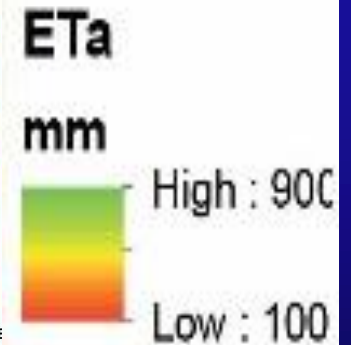
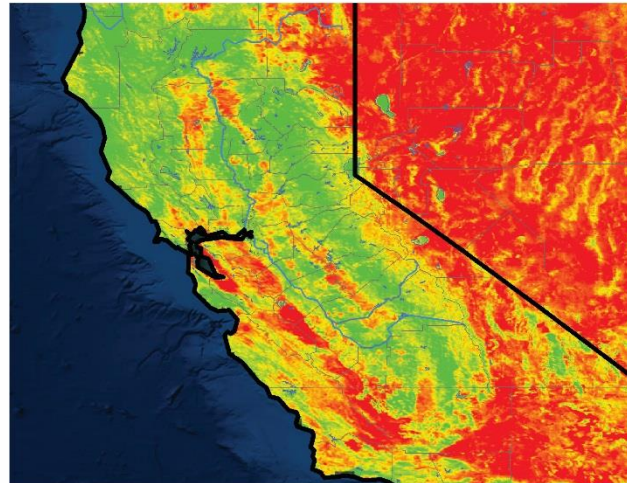
Annual ETa with Daymet vs TopoWx Air Temperature



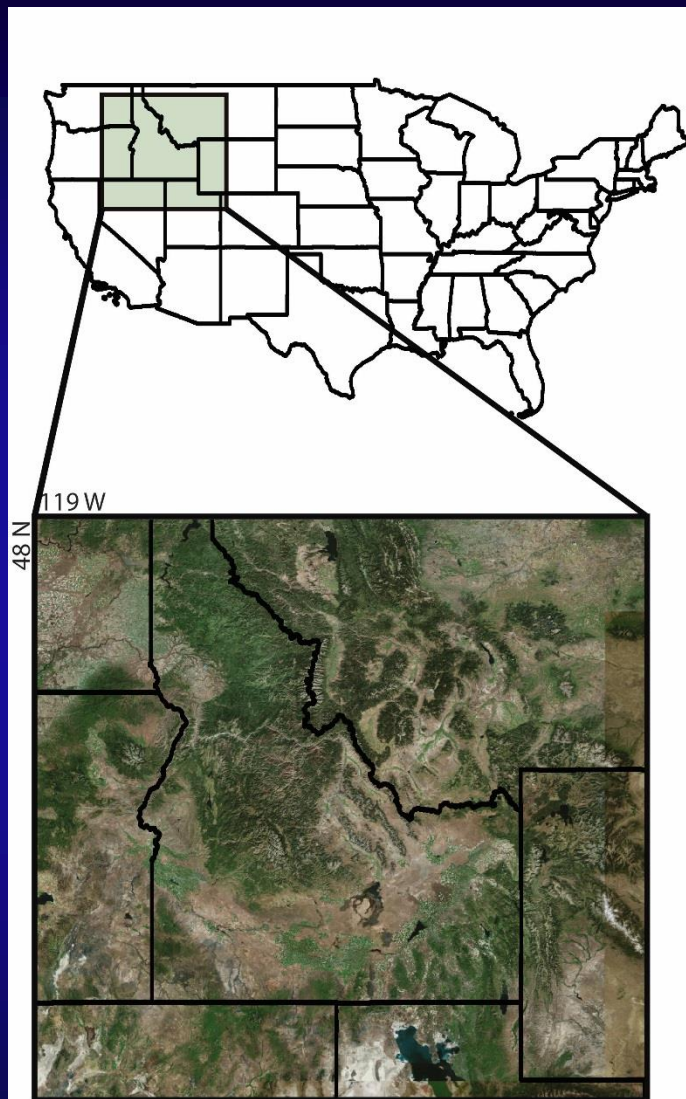
ETa using Daymet Air Temperature (2010)



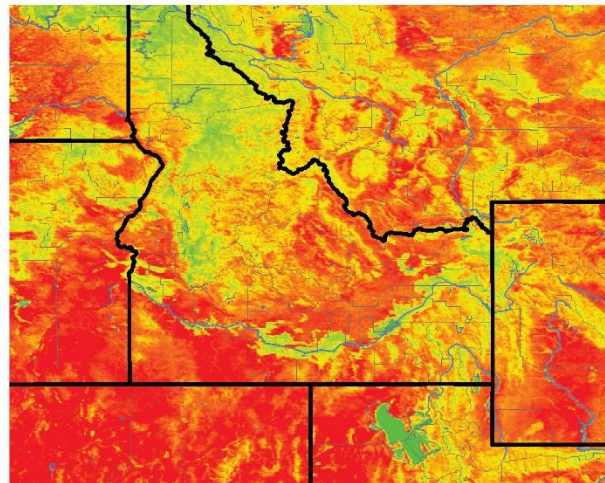
ETa using TopoWX Air Temperature (2010)



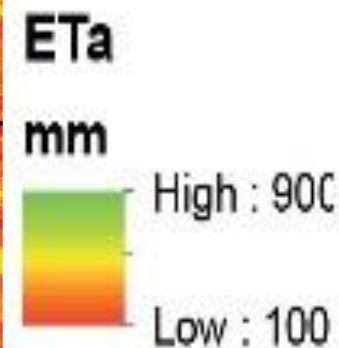
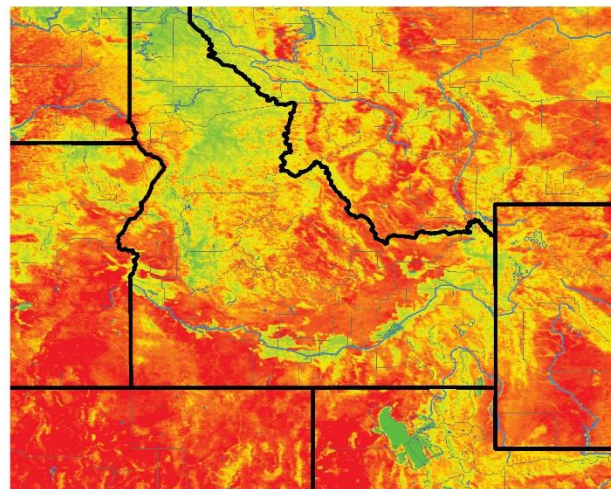
Annual ETa with Daymet vs TopoWx Air Temperature



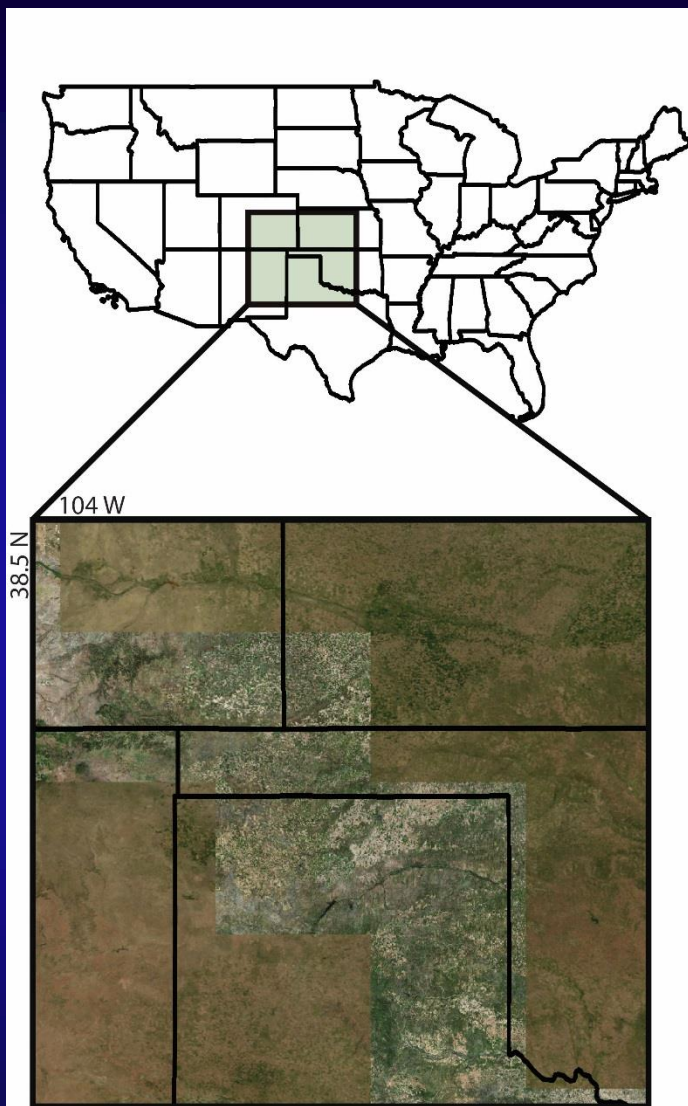
ETa using Daymet Air Temperature (2010)



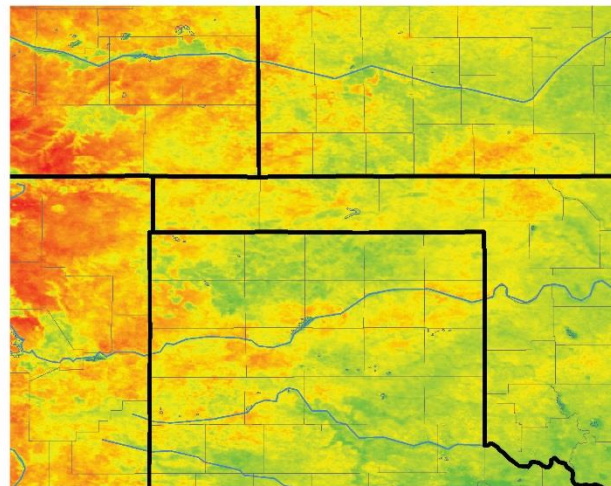
ETa using TopoWX Air Temperature (2010)



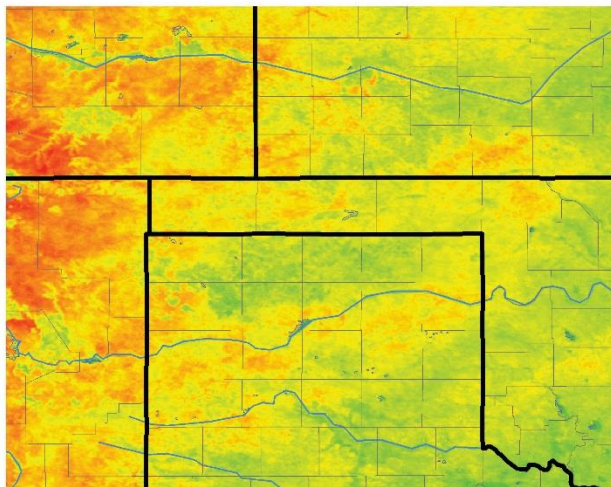
Annual ETa with Daymet vs TopoWx Air Temperature



ETa using Daymet Air Temperature (2010)



ETa using TopoWX Air Temperature (2010)



ETa

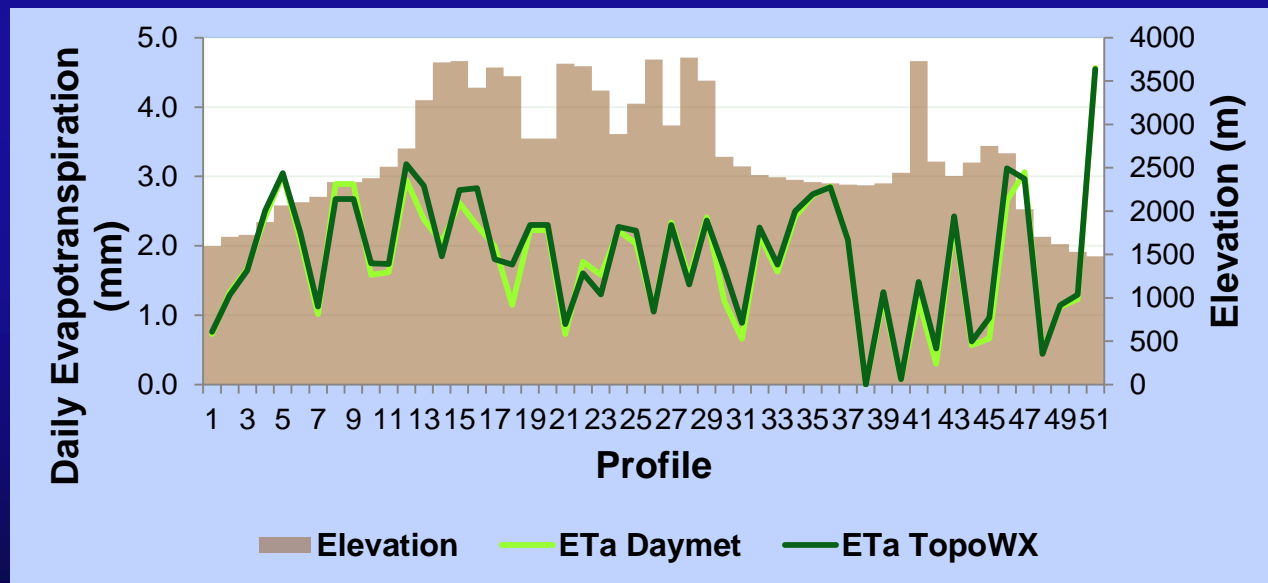
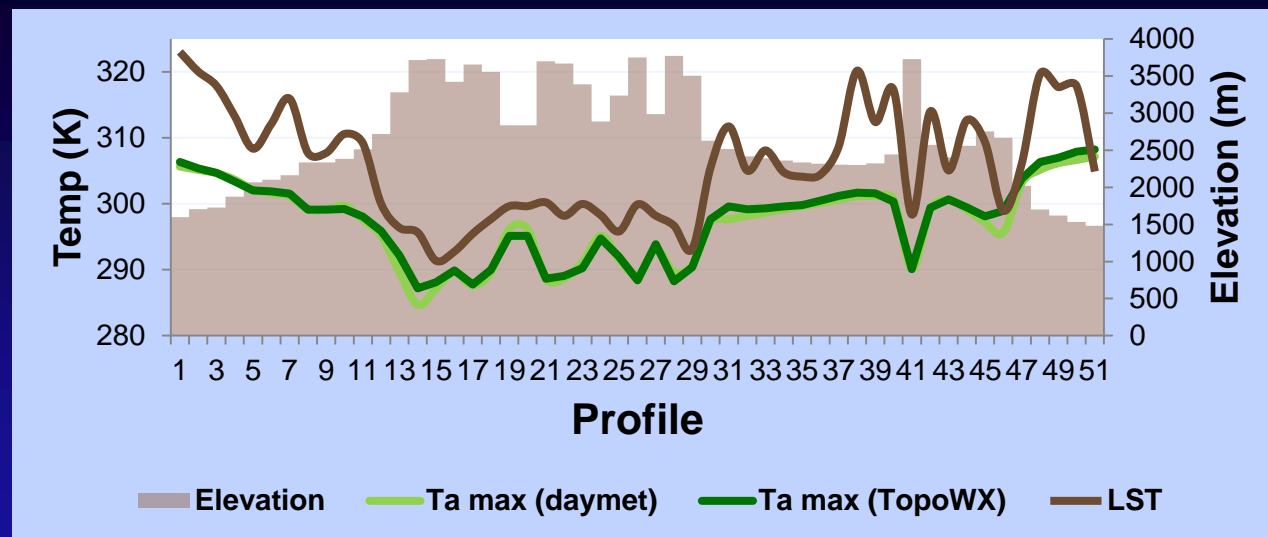
mm

High : 900

Low : 100



Ta, LST and ET along a Transect...

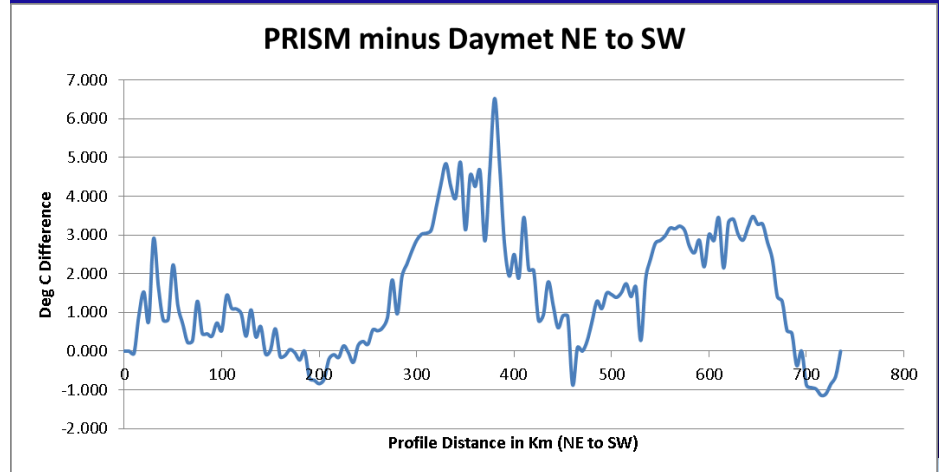
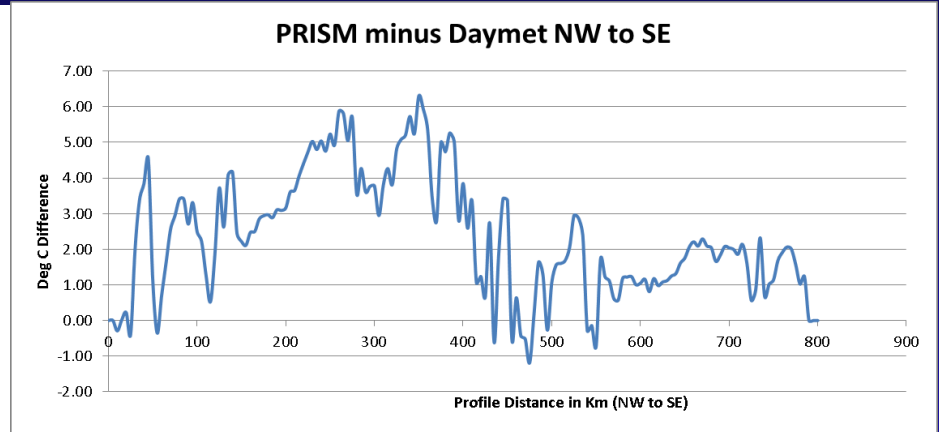
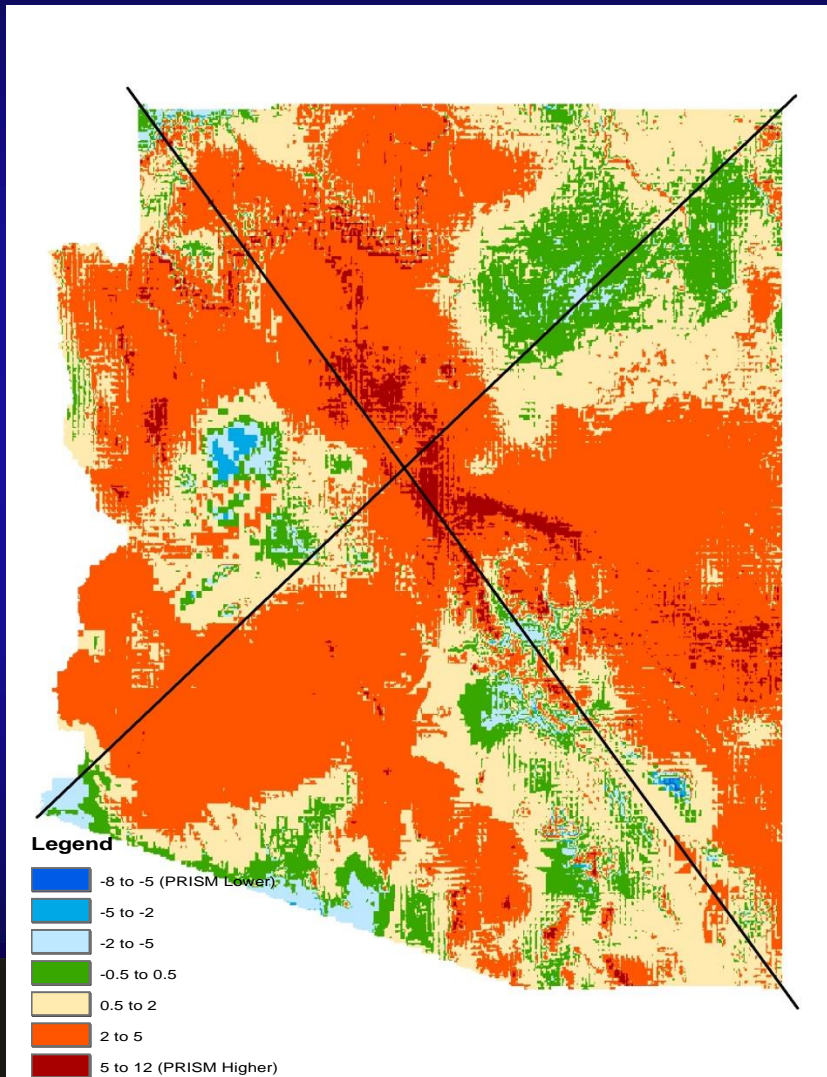


July 4, 2010

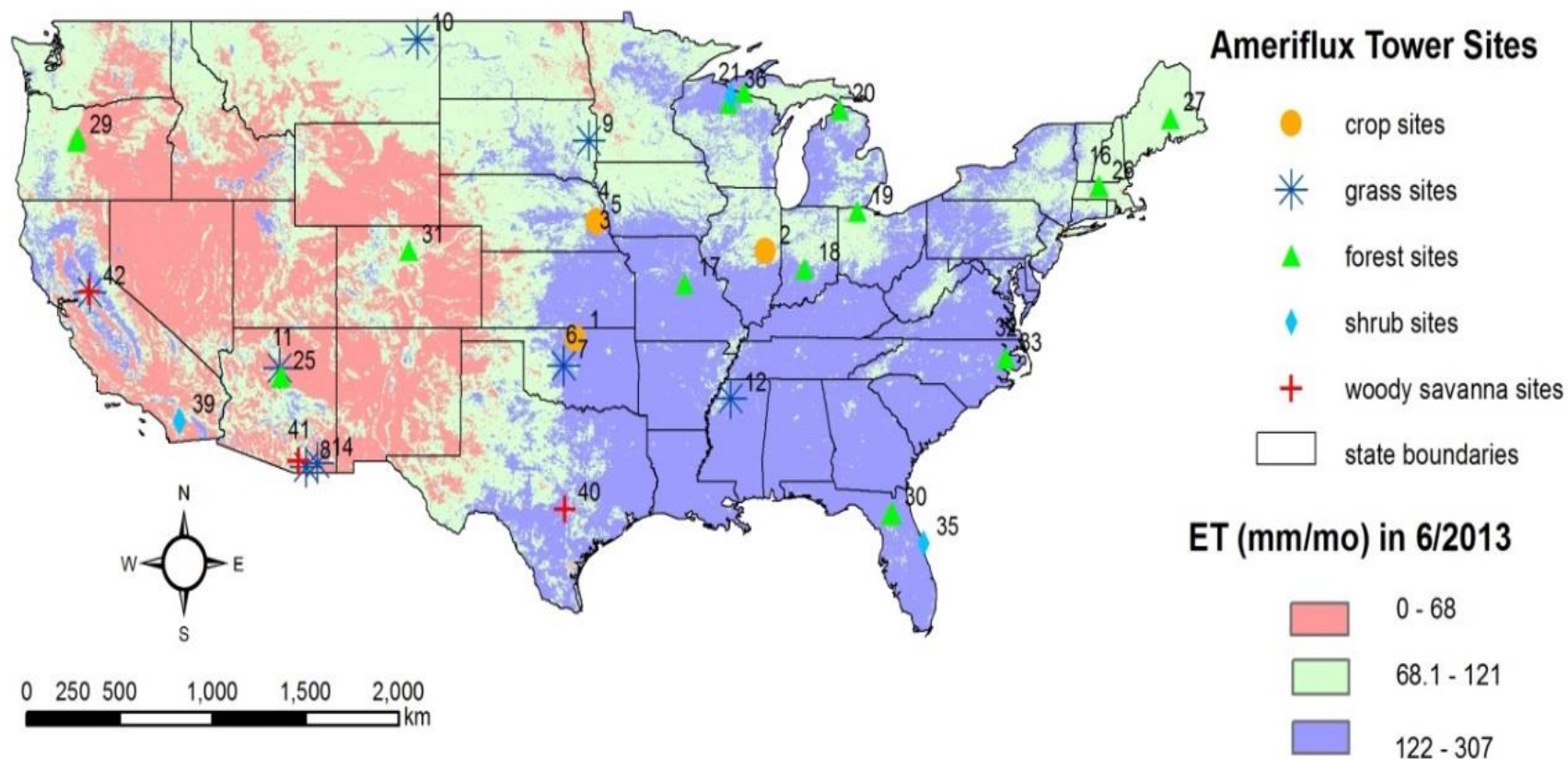


Caution: marked difference between PRISM and Daymet in Arizona, one day example

PRISM minus Daymet - 7/4/2012



Validation with EC Flux Towers

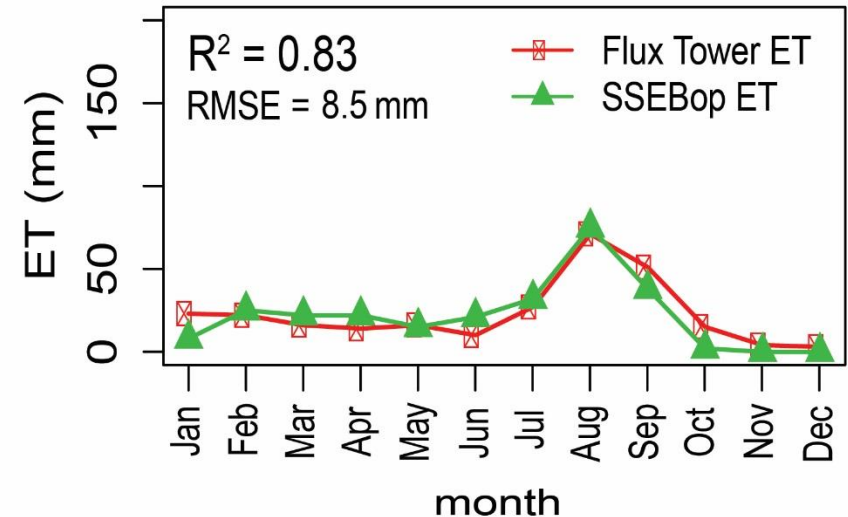
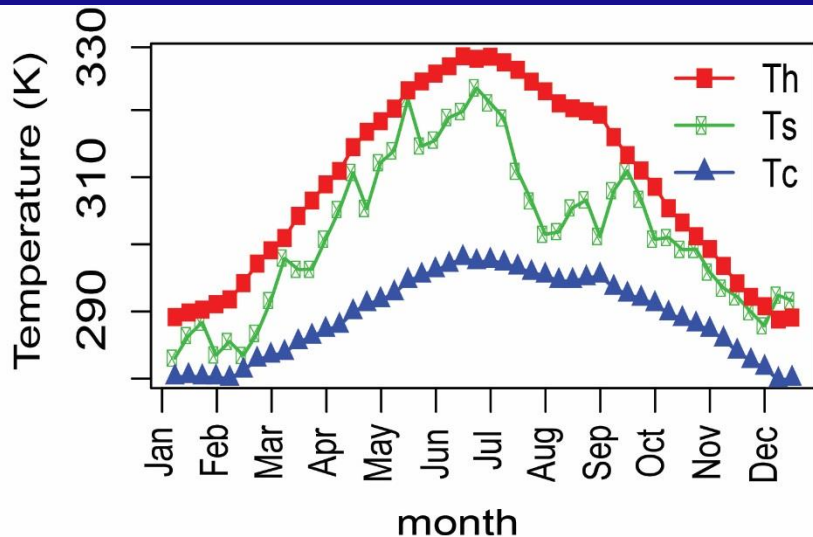


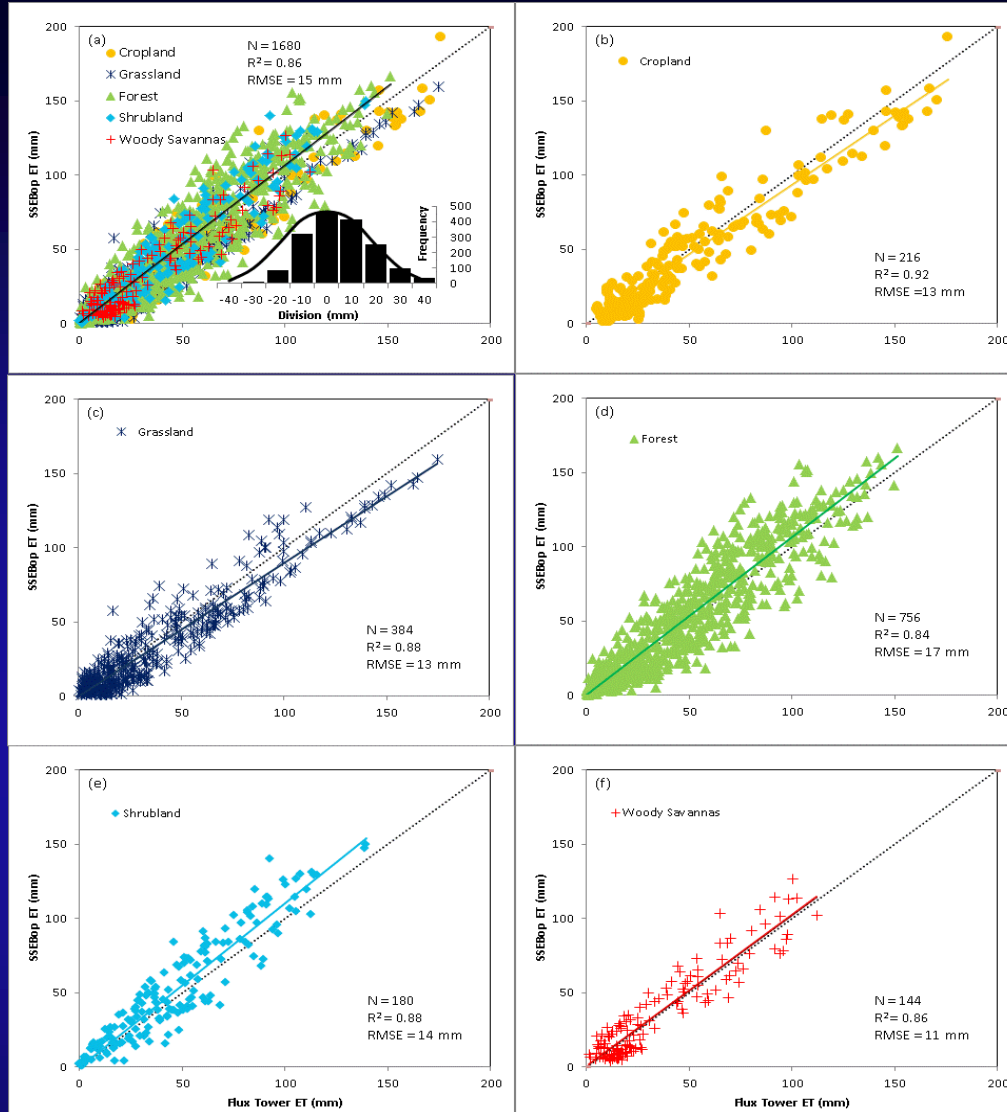
- 42 Ameriflux tower stations (2001-2007) with five land cover types—crop, grass, forest, shrub and woody savanna. The background color represents the ET range for June 2013.



SSEBop Illustrative Validation with EC Flux Towers

EC Flux Tower: Audubon, AZ, 2005



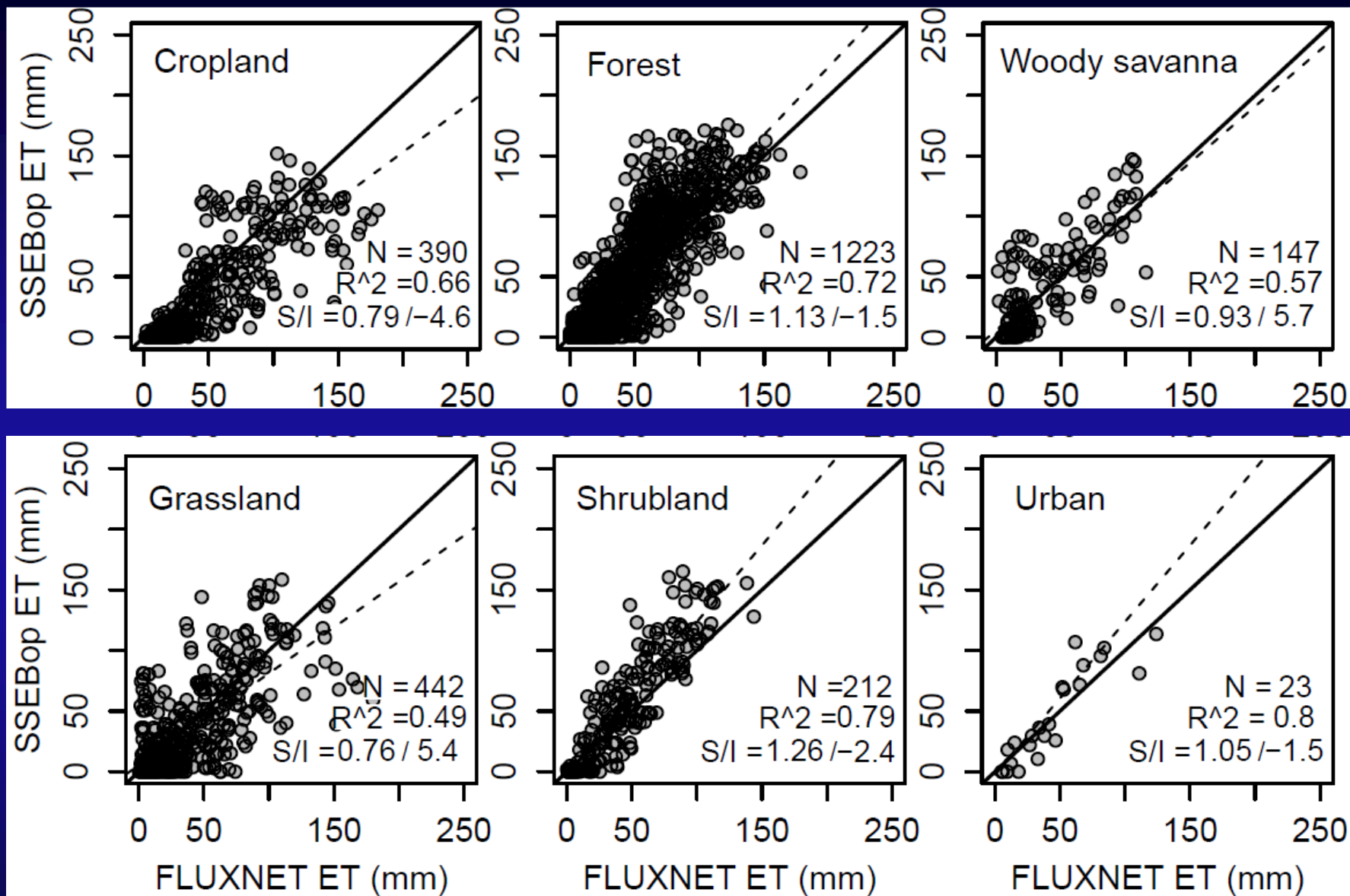


Chen et al, 2015.*
Under preparation

*uses station air temperature

- Scatterplot between mean monthly ET (mm month^{-1}) from the SSEBop and the ET measurements by eddy covariance method across 42 Ameriflux tower sites during 2001 – 2007.

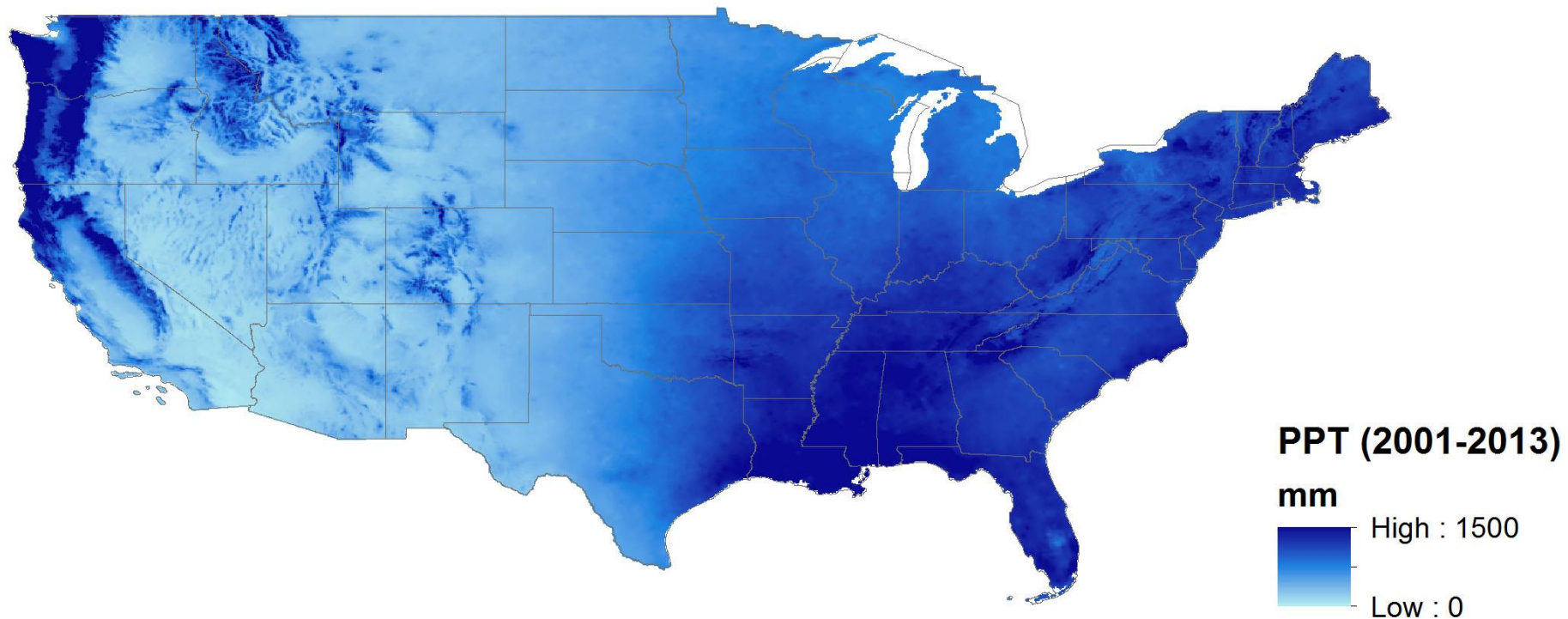




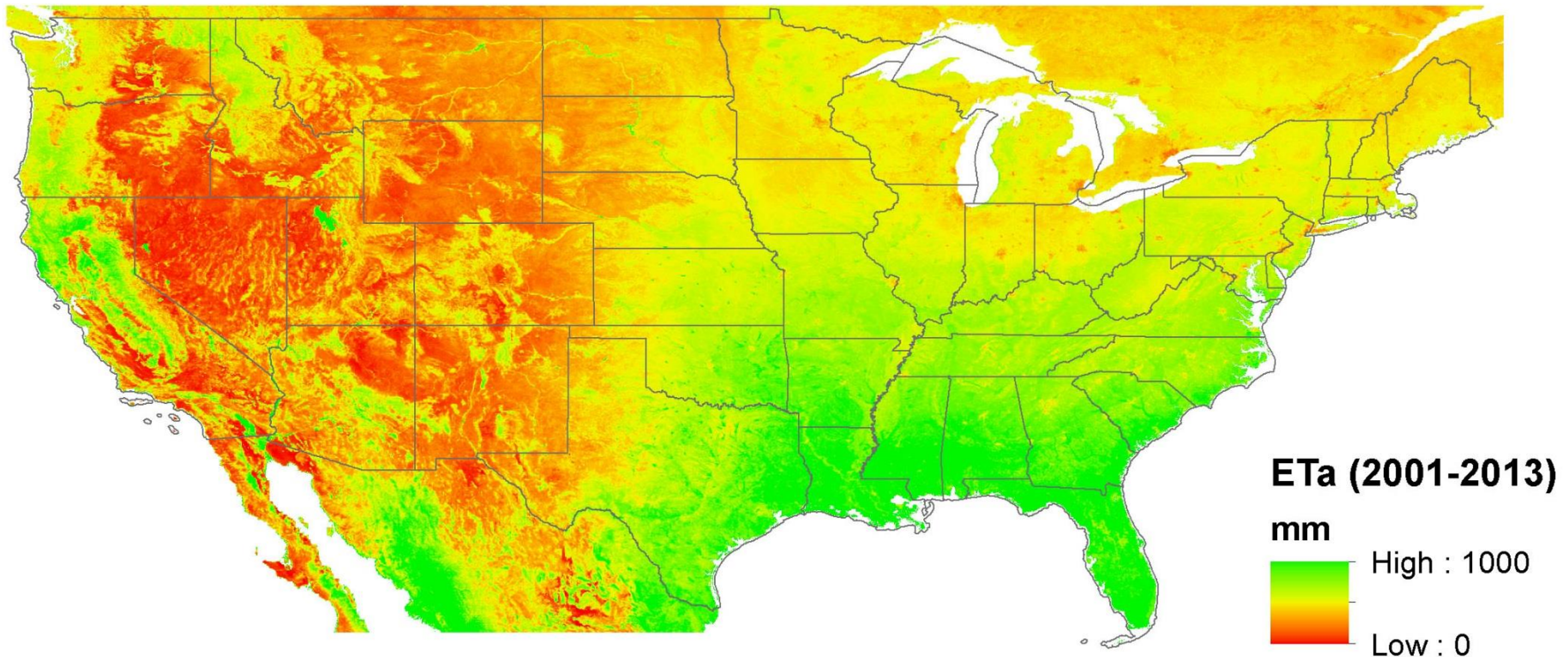
Water Budget Analysis...



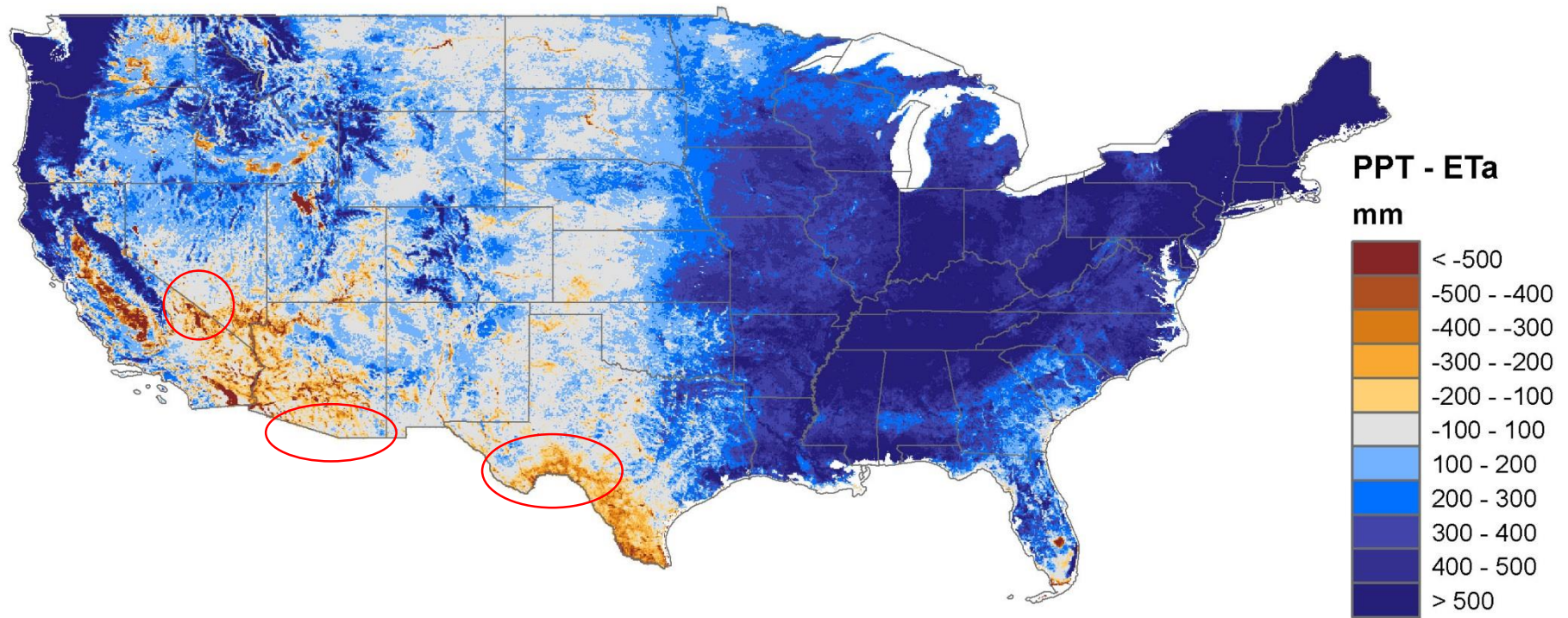
Annual Precipitation (mm) (Median of 2001-2013, PRISM)



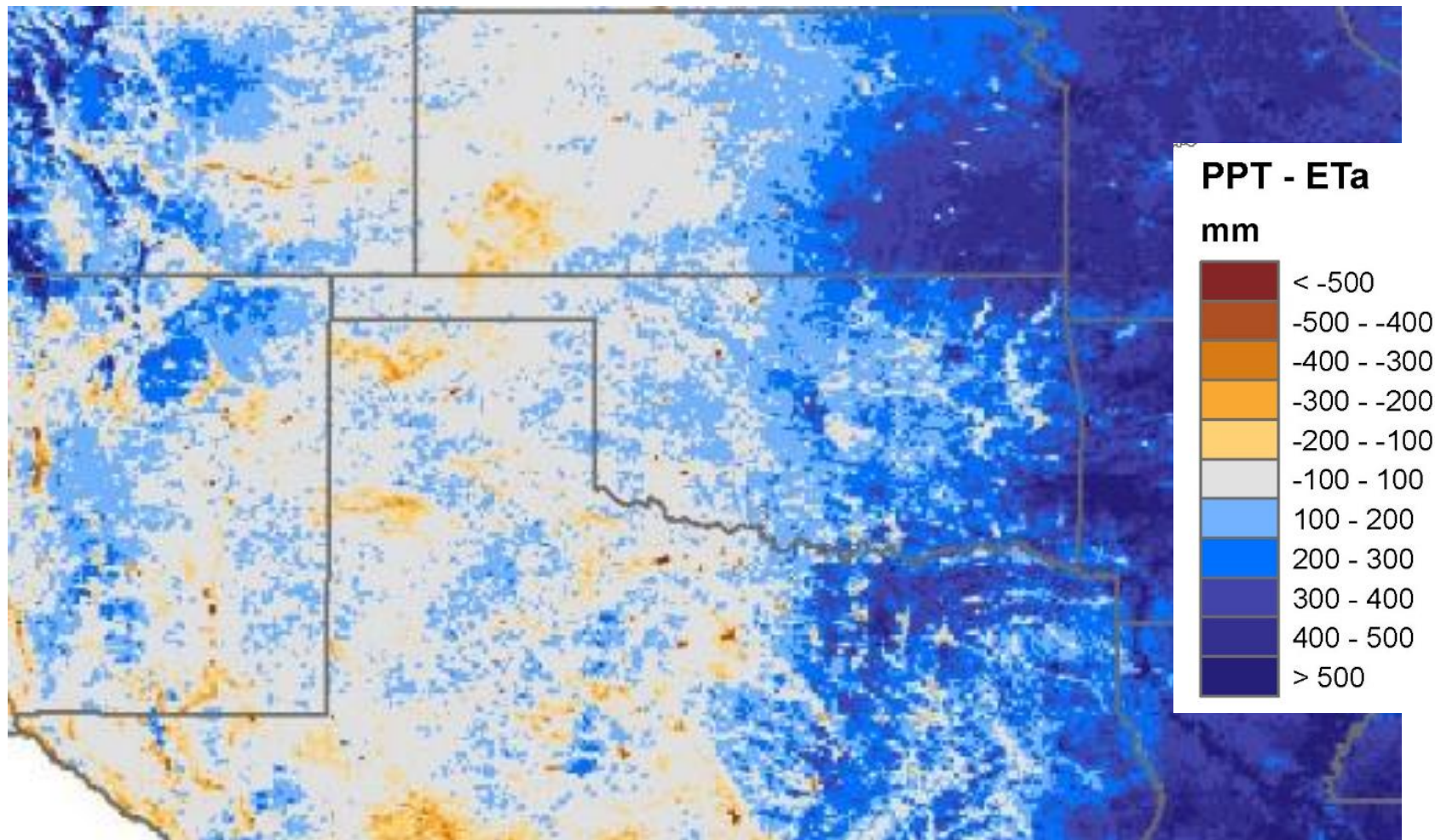
Annual ETa Distribution (mm) (median of 2001-2013, SSEBop)



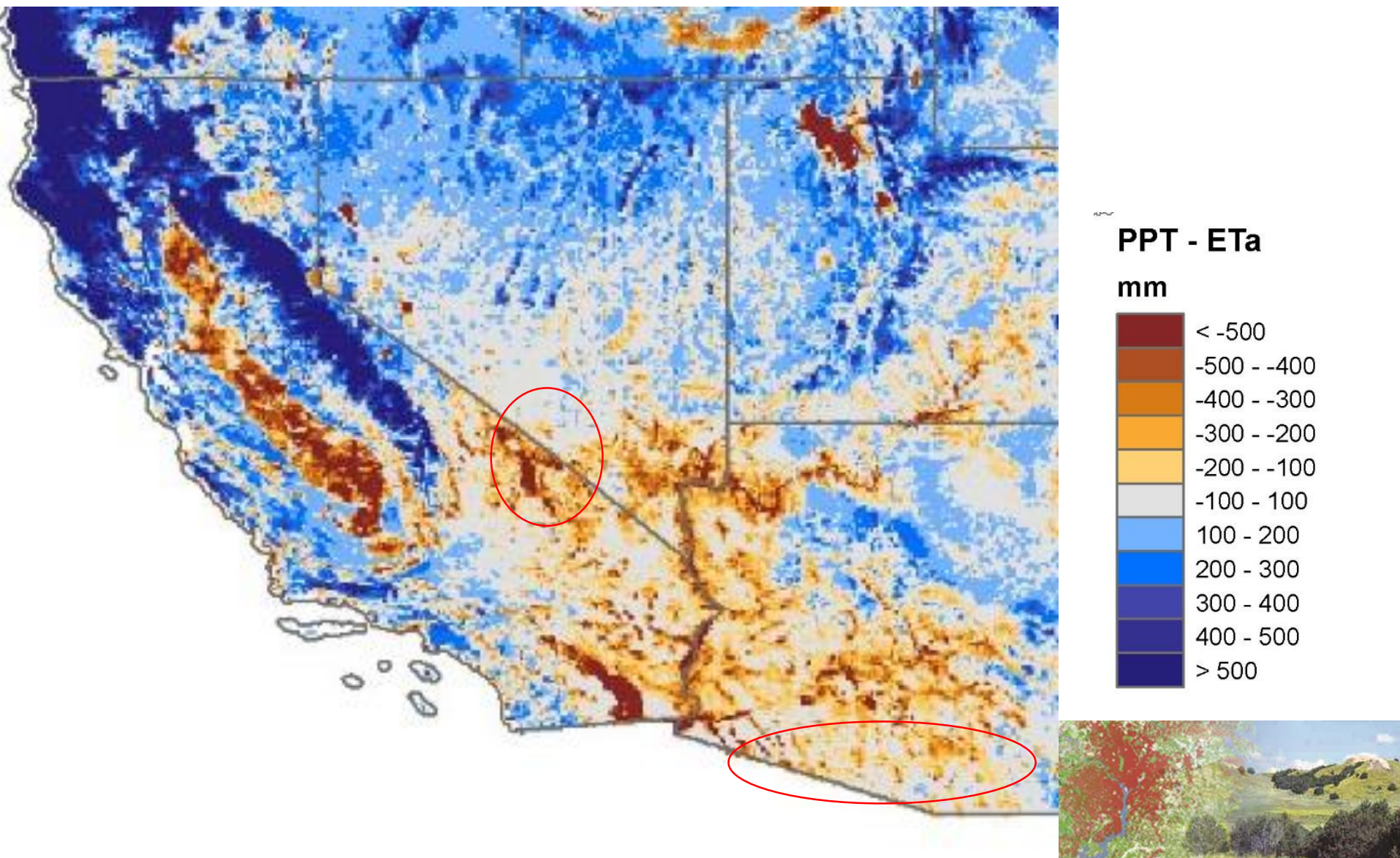
Precipitation minus ETa (mm) (Median of 2001-2013, annual)



Precipitation minus ETa (mm) (Median of 2001-2013, annual)





Precipitation minus ETa (mm) (Median of 2001-2013, annual)



Global and Regional Operational Products

ET anomalies are created as percent deviation (ratio) from the **median over (2003-2013)** ET datasets.



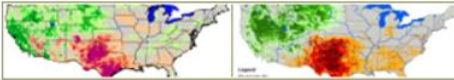


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Early Warning and Environmental Monitoring Program

Early Warning and Environmental Monitoring Program (EWEM)

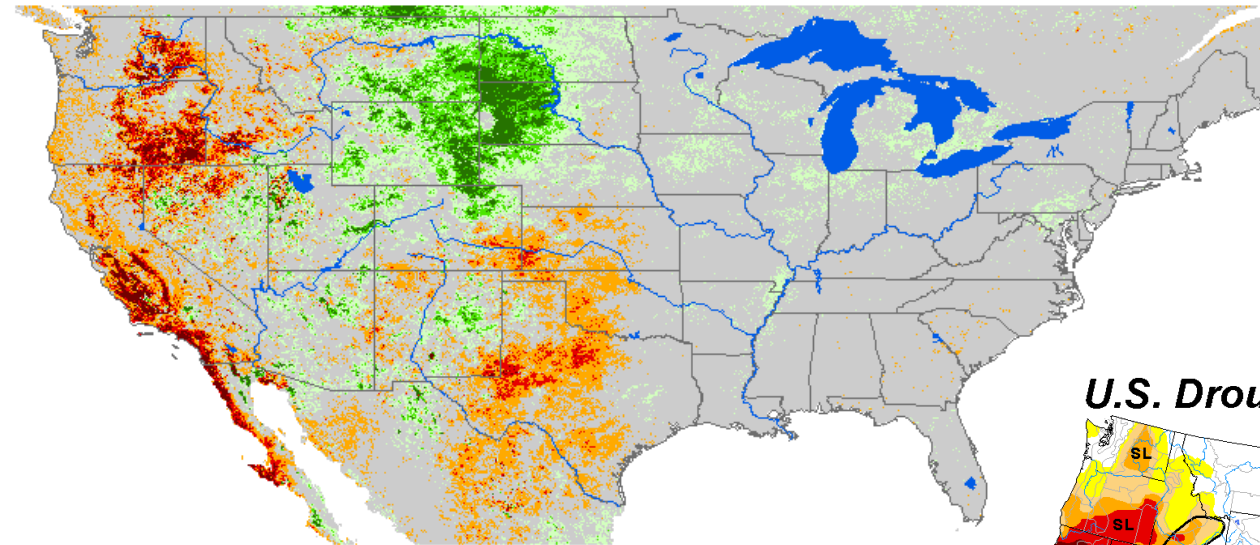
The Early Warning and Environmental Monitoring (EWEM) program encompasses a broad spectrum of scientific endeavors operating at national, regional, and international scales. EWEM project activities support investigations in the areas of climate change, natural resource management, environmental change detection, food security monitoring, water resource assessments, and hazard identification/mitigation.

Projects	Websites
Afghanistan	
Famine Early Warning Systems Network (FEWS NET)	
US Evapotranspiration Modeling Water Balance Model - Energy Balance Model	
NASA Livestock Early Warning System (NASA LEWS)	

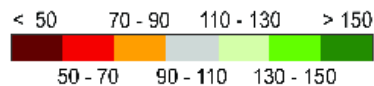
http://earlywarning.usgs.gov/usewem/eta_energy.php

Seasonal sum/anomaly generated from 8-day totals

8-day Cumulative ETa Anomaly 01 Apr - 31 Oct 2014



ETa Anomaly (%)



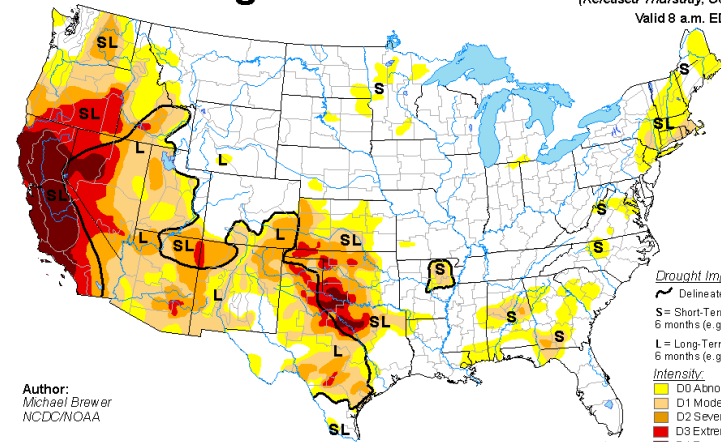
— Rivers ■ Lakes □ State Boundaries

Map produced by USGS/EROS



U.S. Drought Monitor

October 21, 2014
(Released Thursday, Oct. 23, 2014)
Valid 8 a.m. EDT



Drought Impact Types:

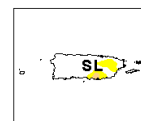
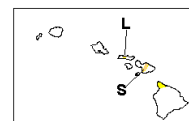
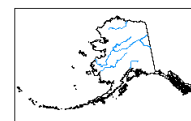
~ Delineates dominant impacts
S = Short-Term, typically less than 6 months (e.g. agriculture, grasslands)
L = Long-Term, typically greater than 6 months (e.g. hydrology, ecology)

Intensity:

D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought

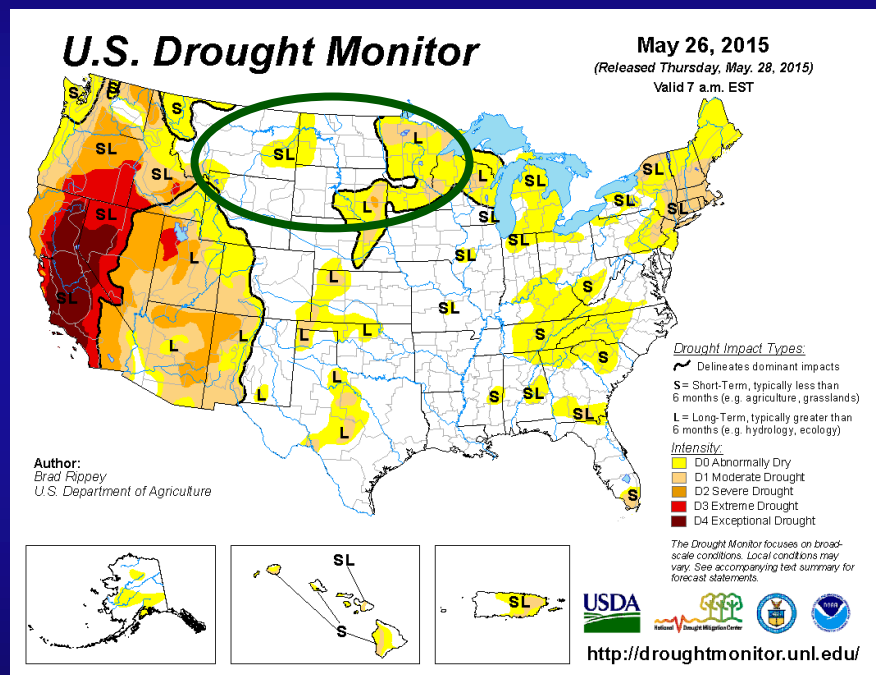
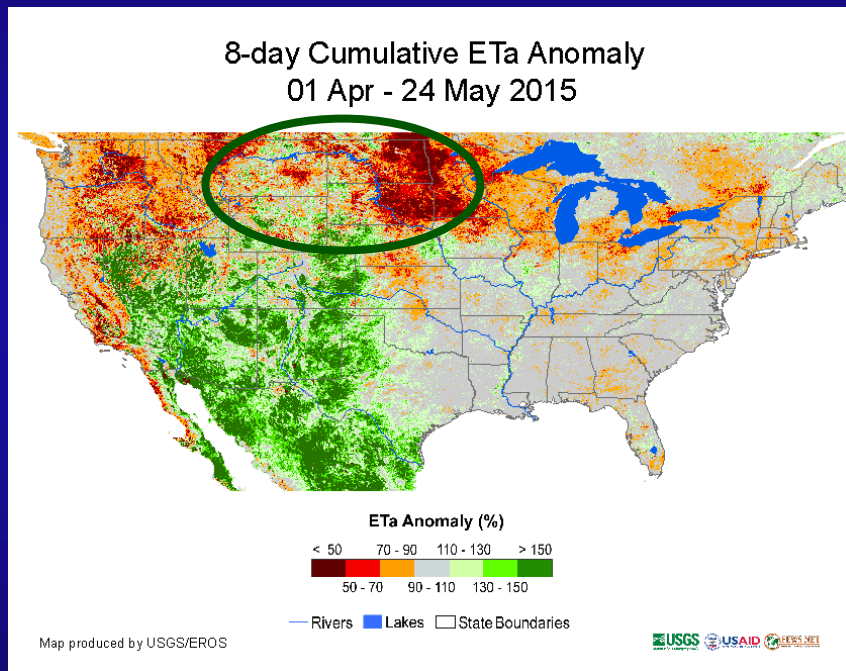
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Michael Brewer
NCDC/NOAA



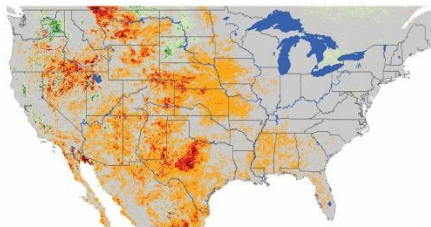
<http://droughtmonitor.unl.edu/>

Most recent condition in the US

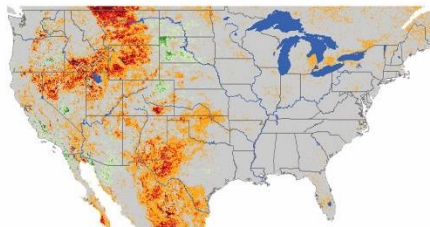


Major difference in green circle, maybe too early in season

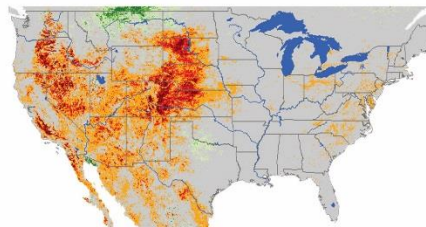
2000



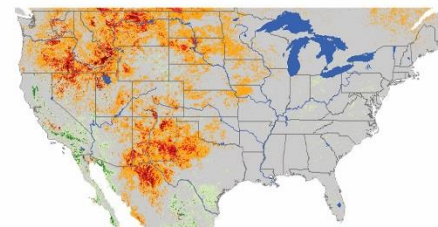
2001



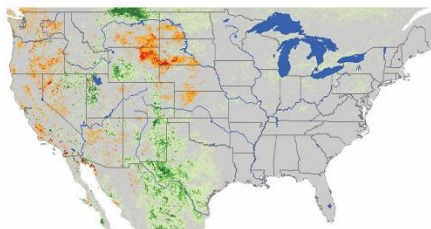
2002



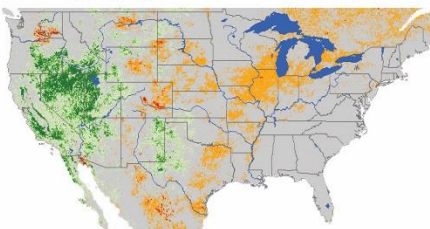
2003



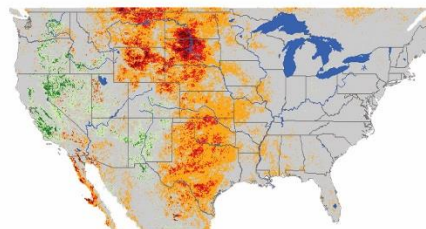
2004



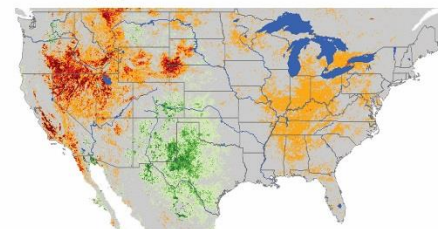
2005



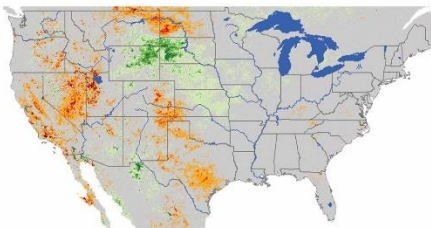
2006



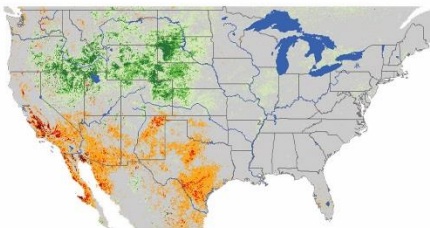
2007



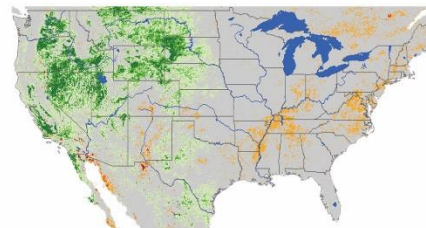
2008



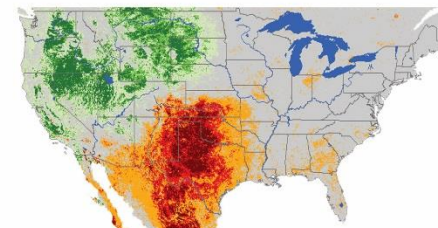
2009



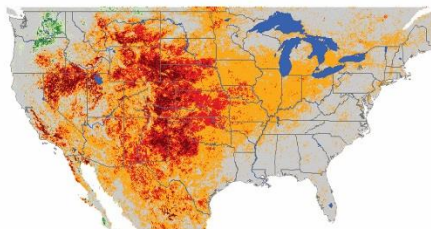
2010



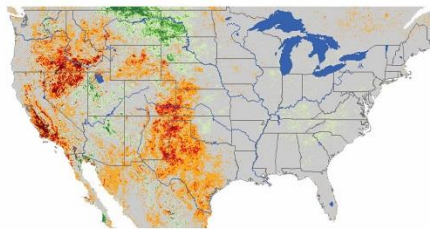
2011



2012



2013



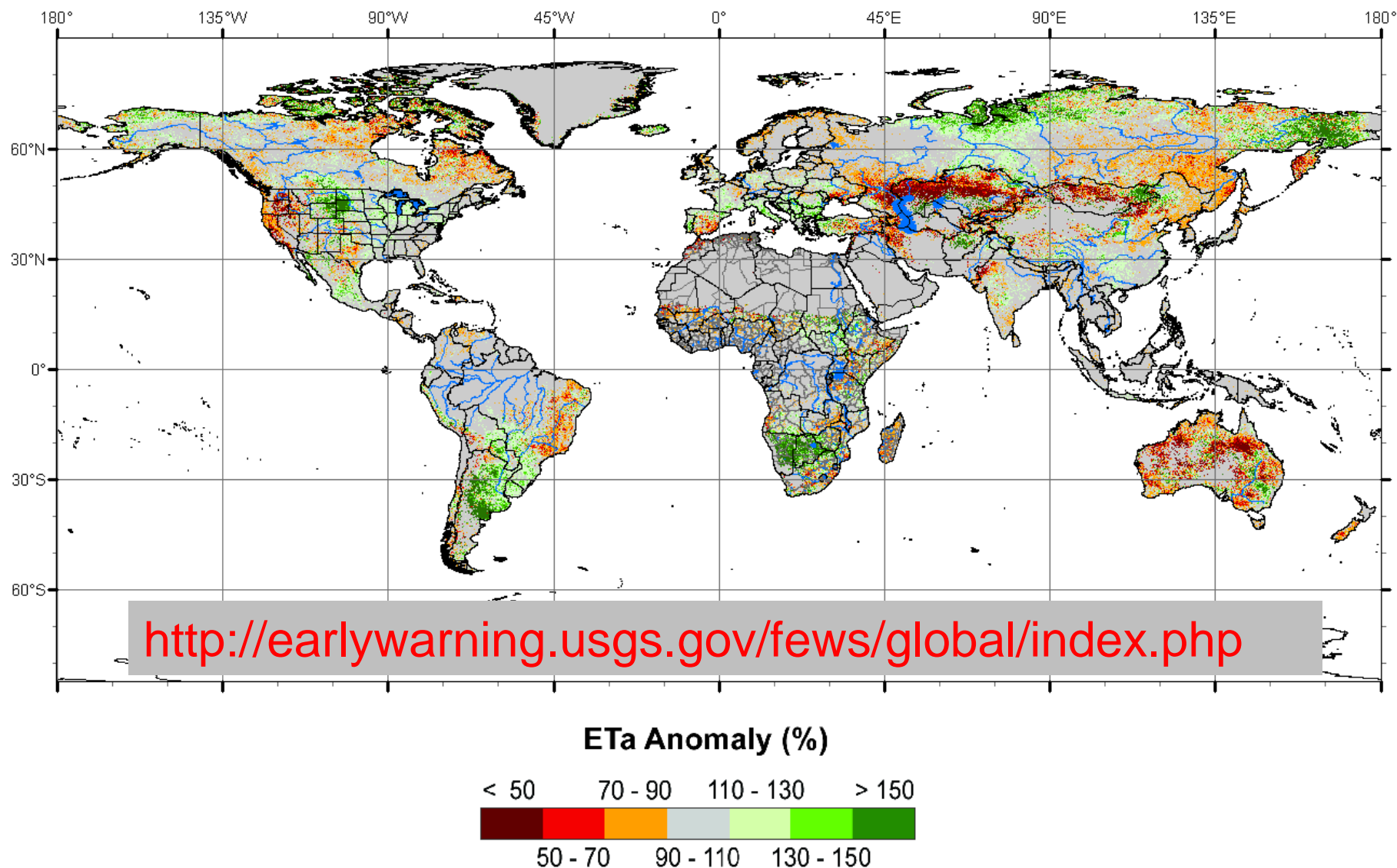
Annual ET Anomaly

ETa Anomaly (%)



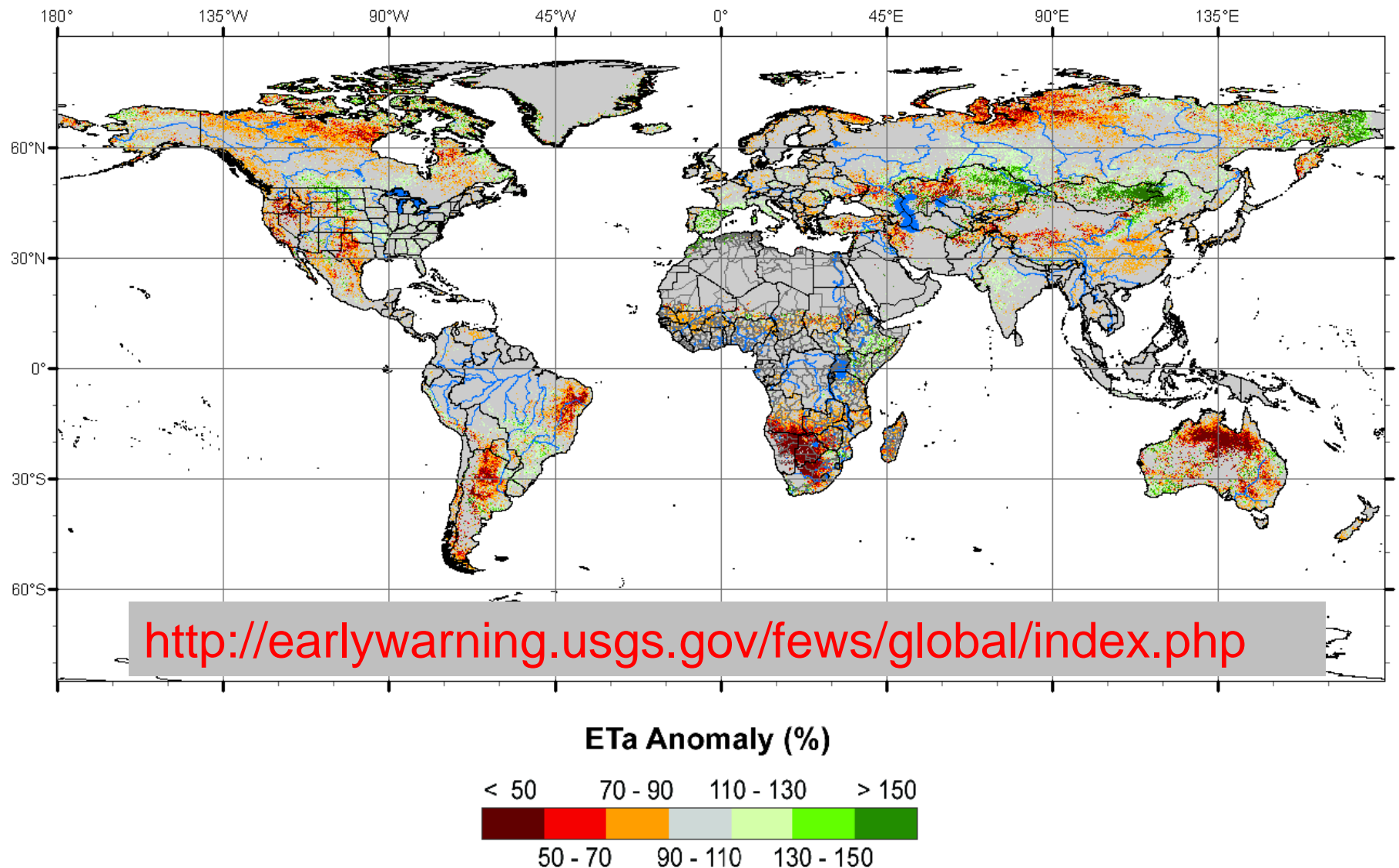
Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 2, 2014

Percent of Median (2003-2013)



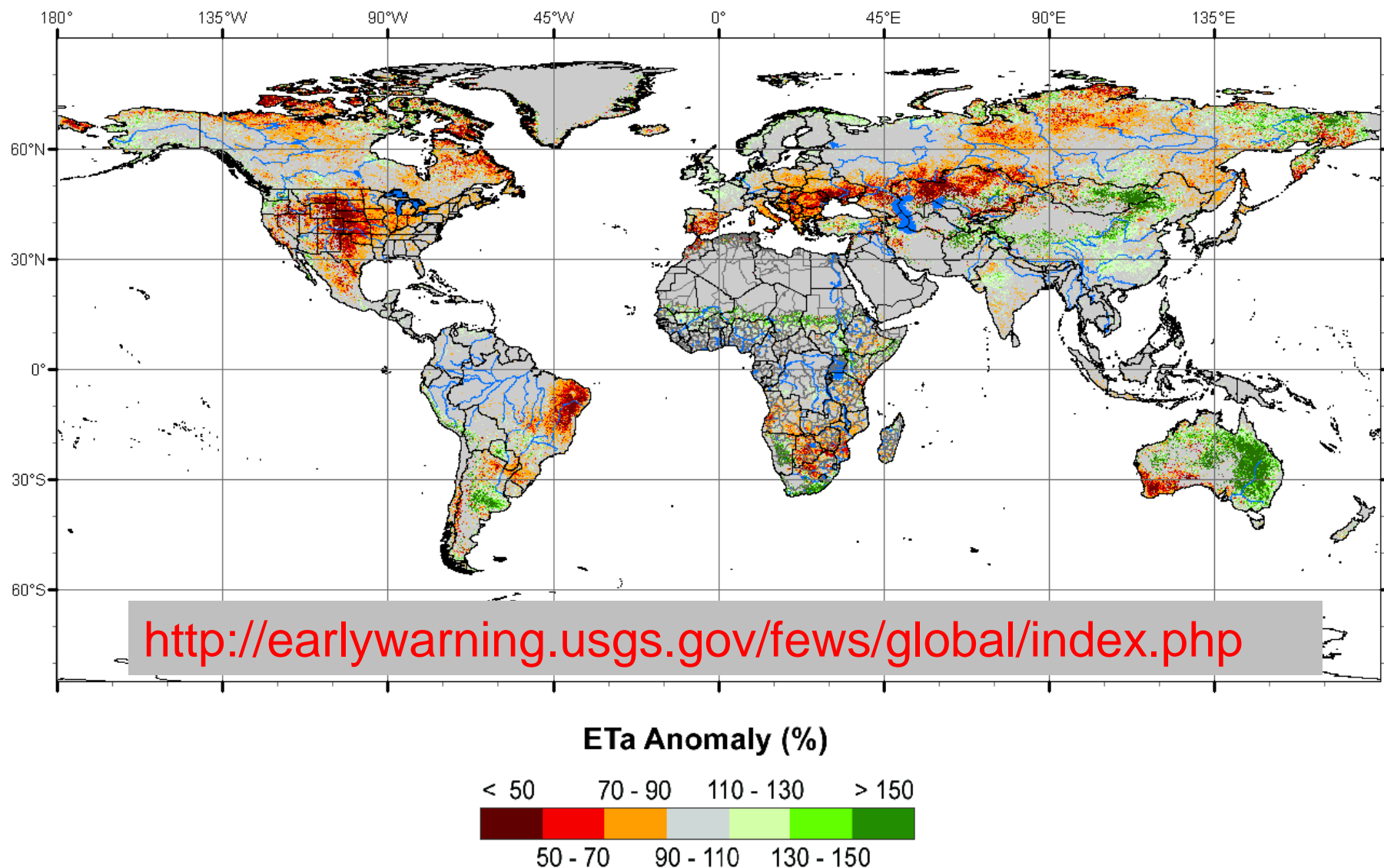
Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2013

Percent of Average (2003-2013)

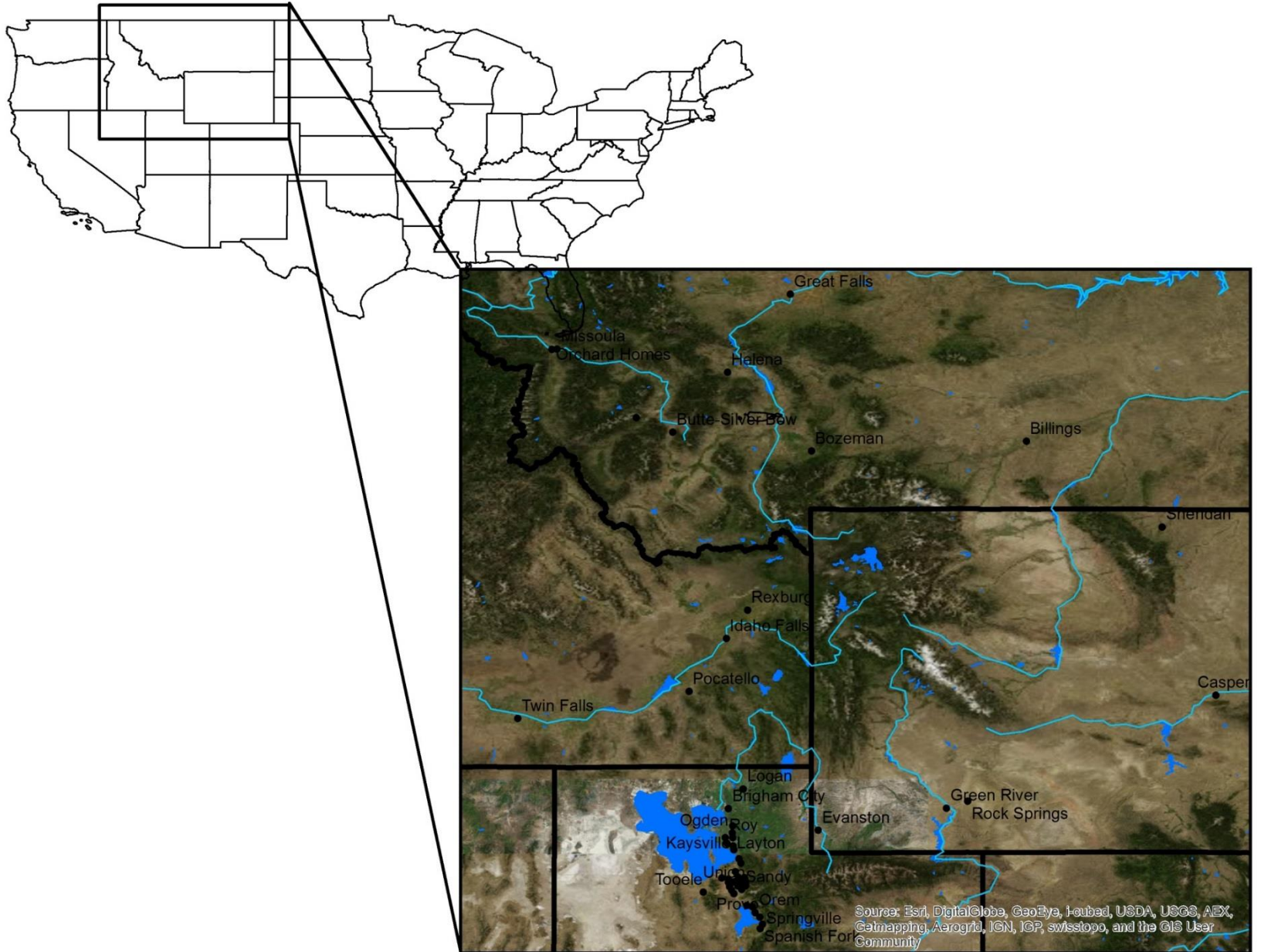


Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2012

Percent of Average (2003-2013)



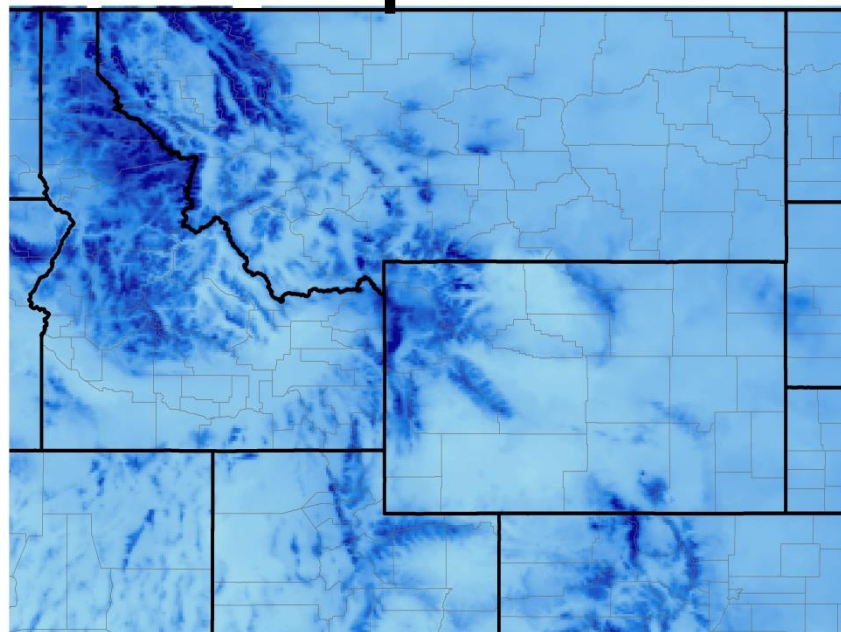
Montana/Wyoming ETa/ETa Anomaly



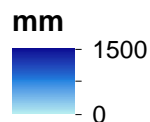
Key Water Balance Components

Precipitation

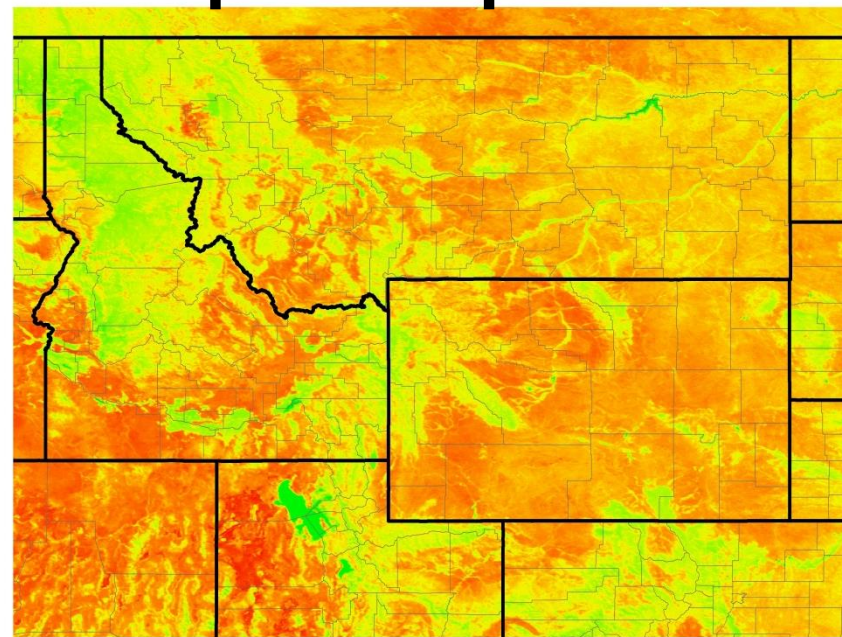
Evapotranspiration



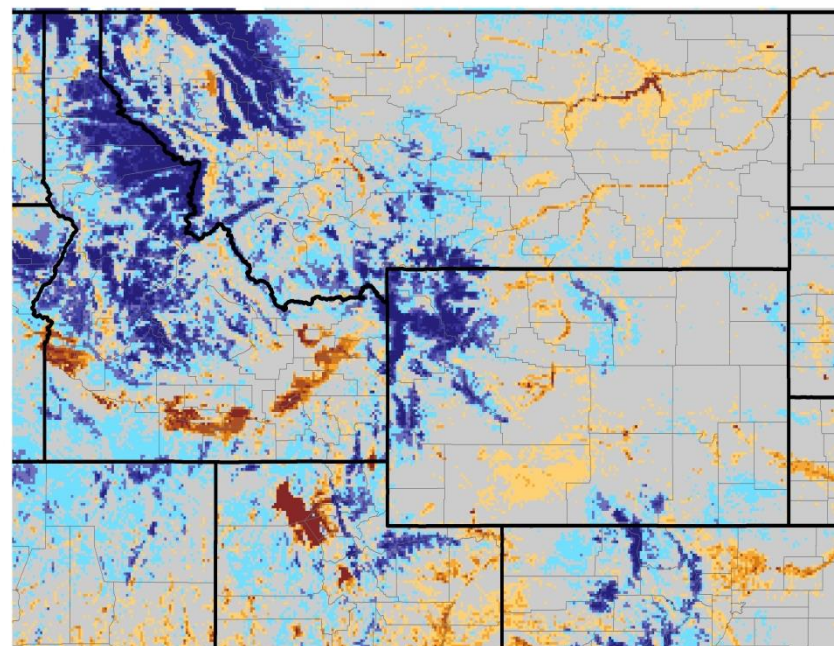
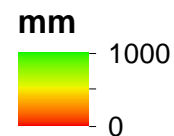
PPT (2001-2013)



PPT source: PRISM

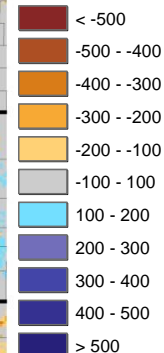


ETa (2001-2013)

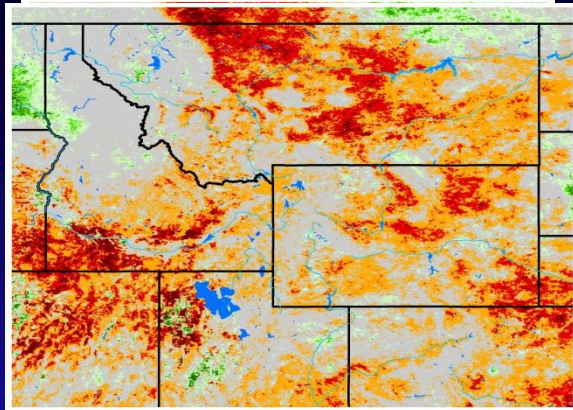


PPT-ETa

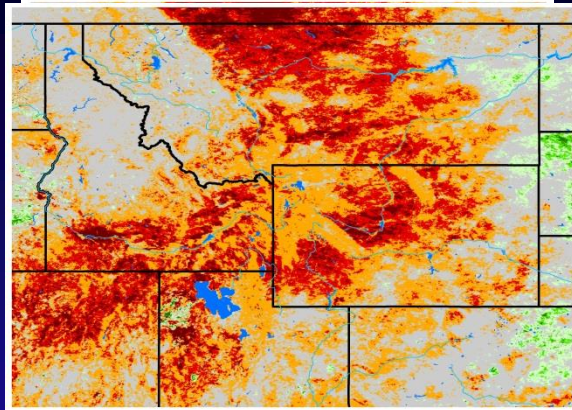
mm



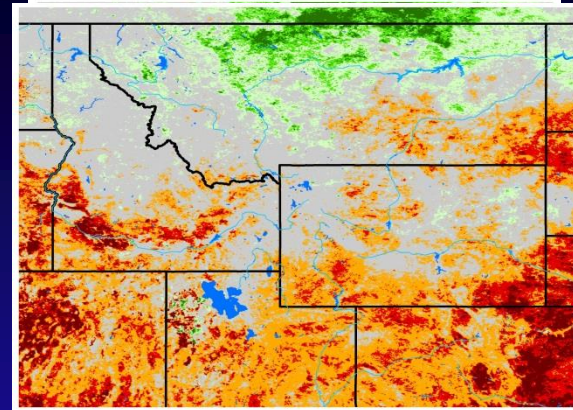
2000



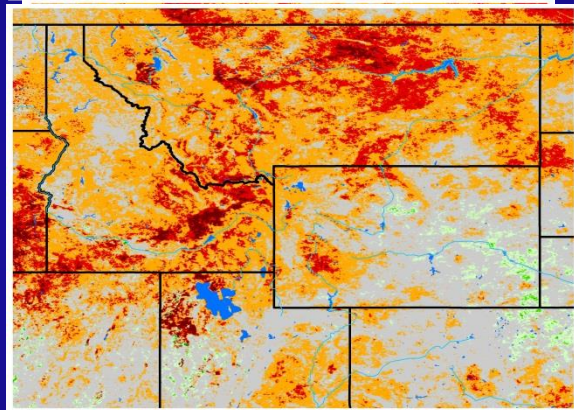
2001



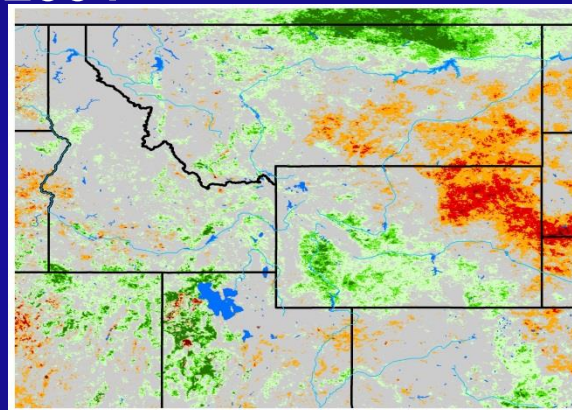
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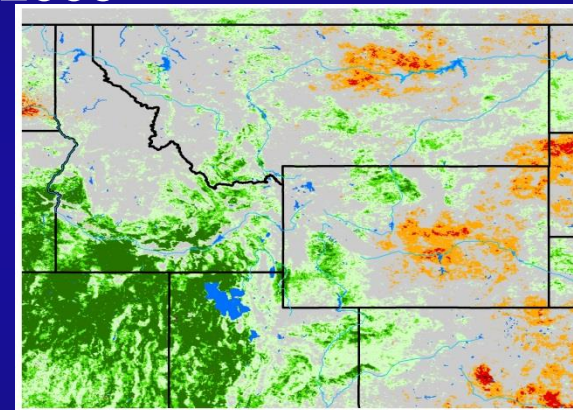
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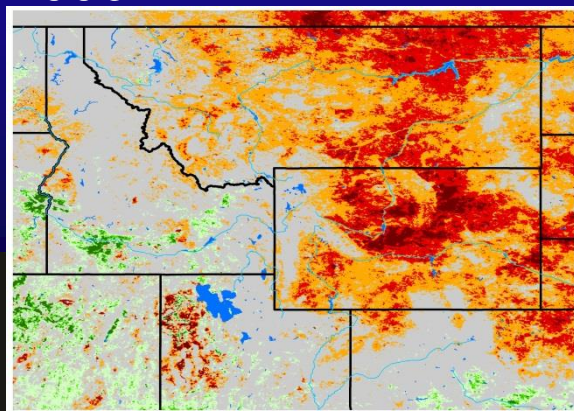
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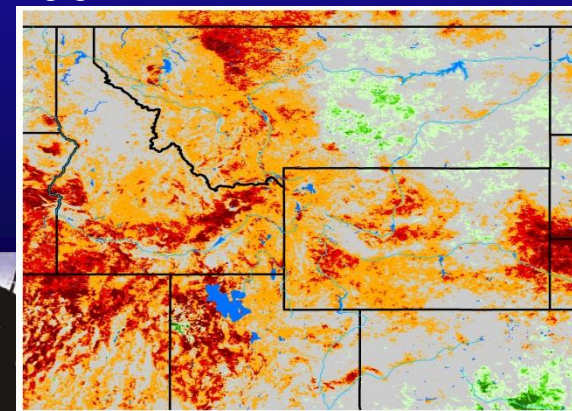
2005



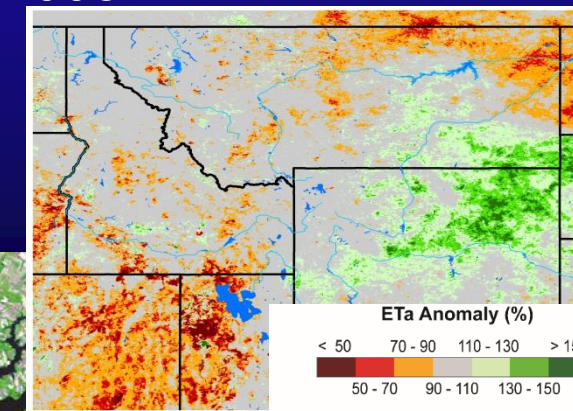
2006



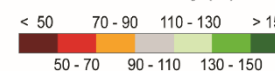
2007



2008

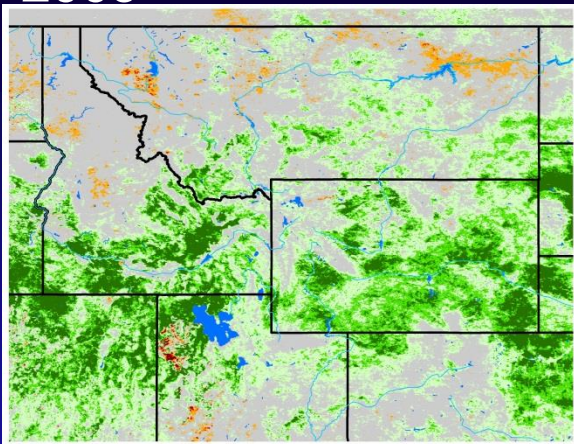


ETa Anomaly (%)

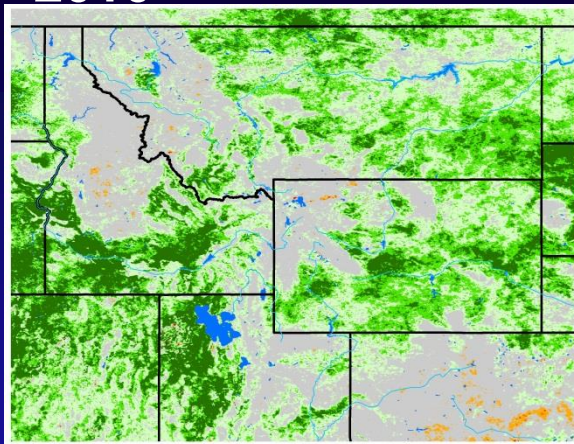


— Rivers — Lakes — State Boundaries

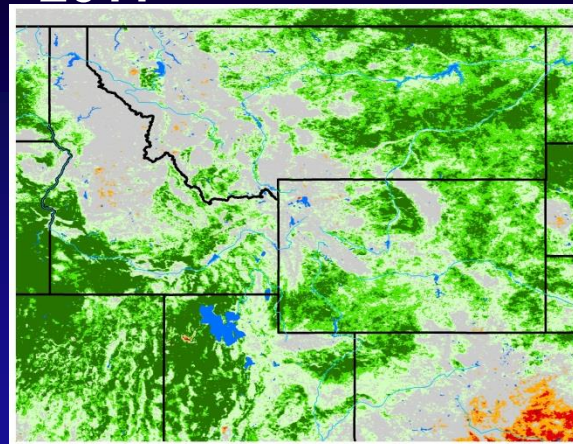
2009



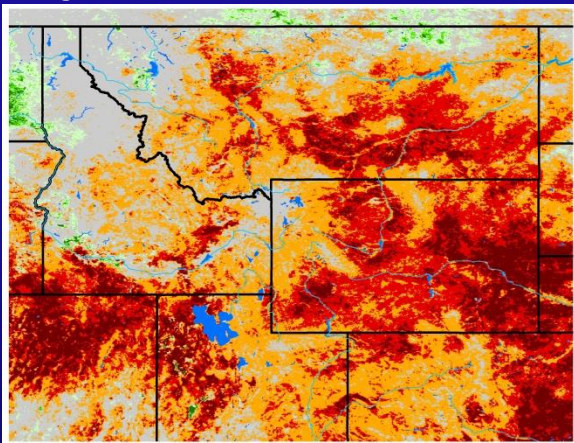
2010



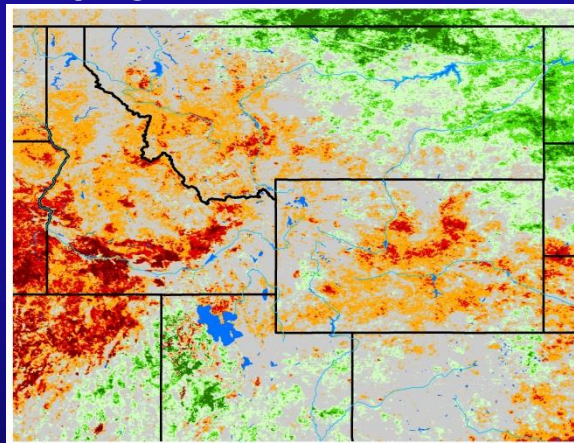
2011



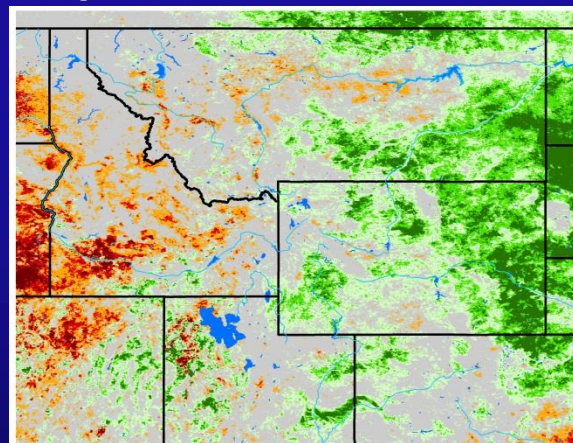
2012



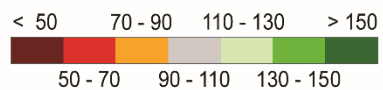
2013



2014



ETa Anomaly (%)



— Rivers ■ Lakes □ State Boundaries



Landsat Scale ET: Water use at a field scale...



Landsat ET

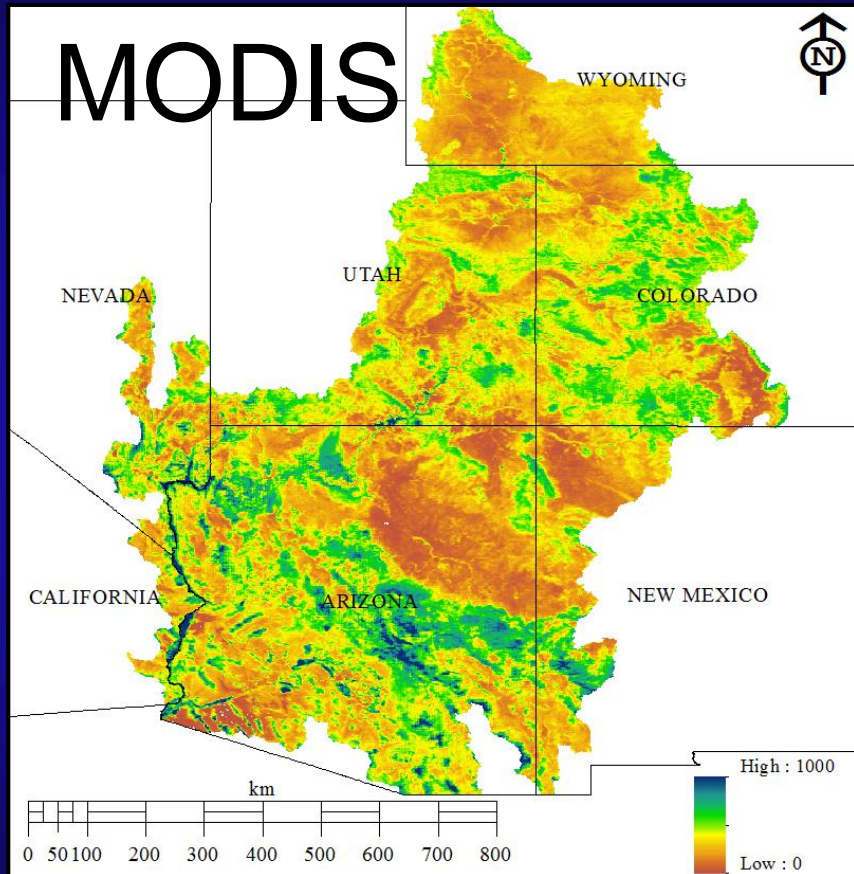
43 Landsat path/row
Scenes to cover
CRB

Clouds Issues:
9 to 15 images
for each are used

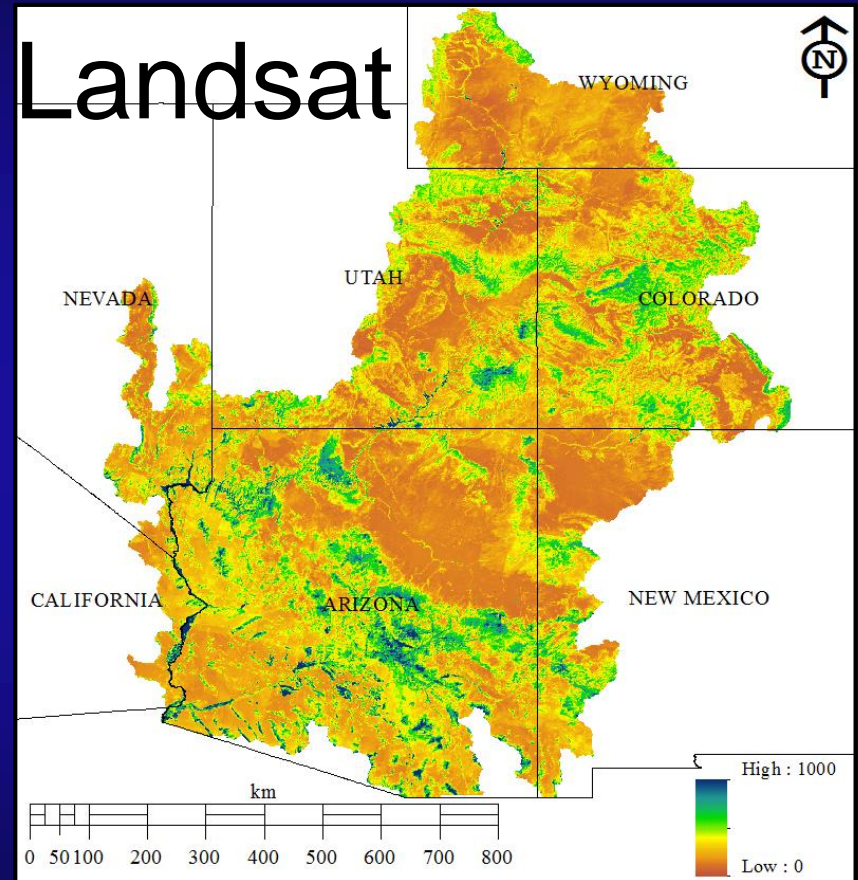
Total = 400 - 500



Colorado River Basin Annual ET 2010 (mm): 1st ever for CRB, seamless Landsat ET!



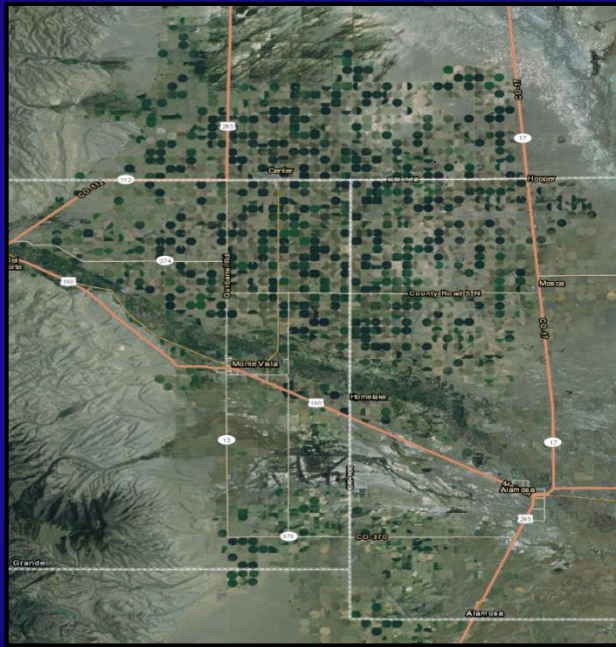
Senay et al, 2013



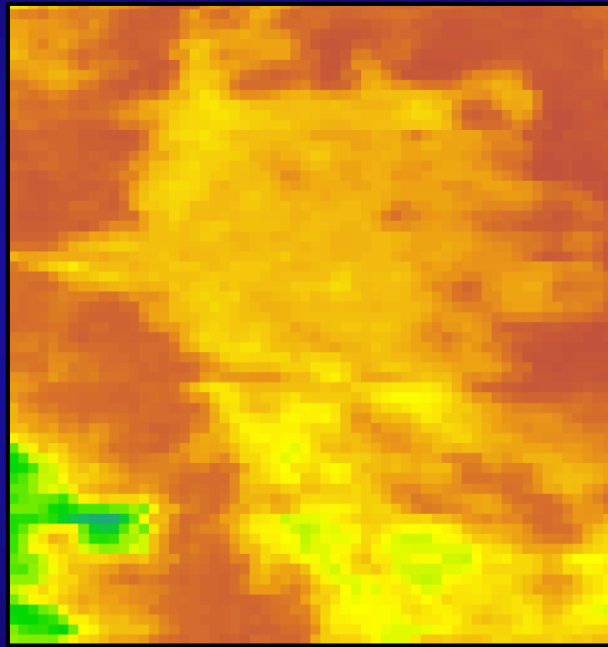
Singh et al, 2014



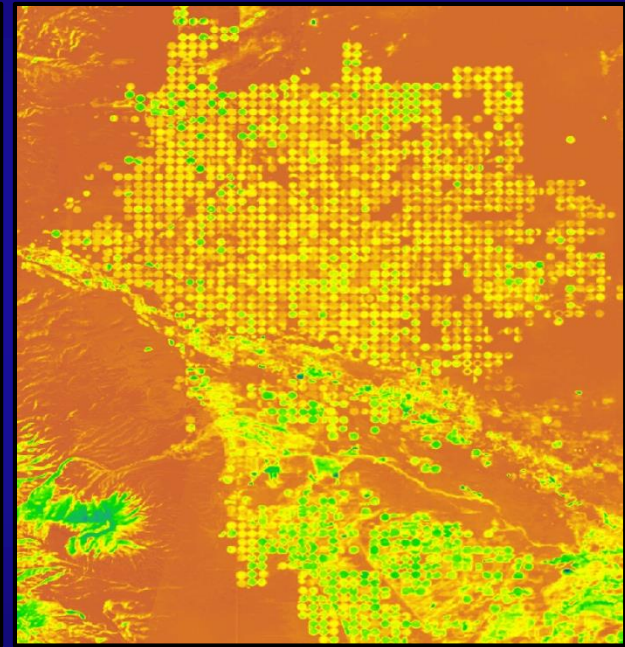
Close up View of MODIS and Landsat Annual ET With Respect to Base Map



Base Map



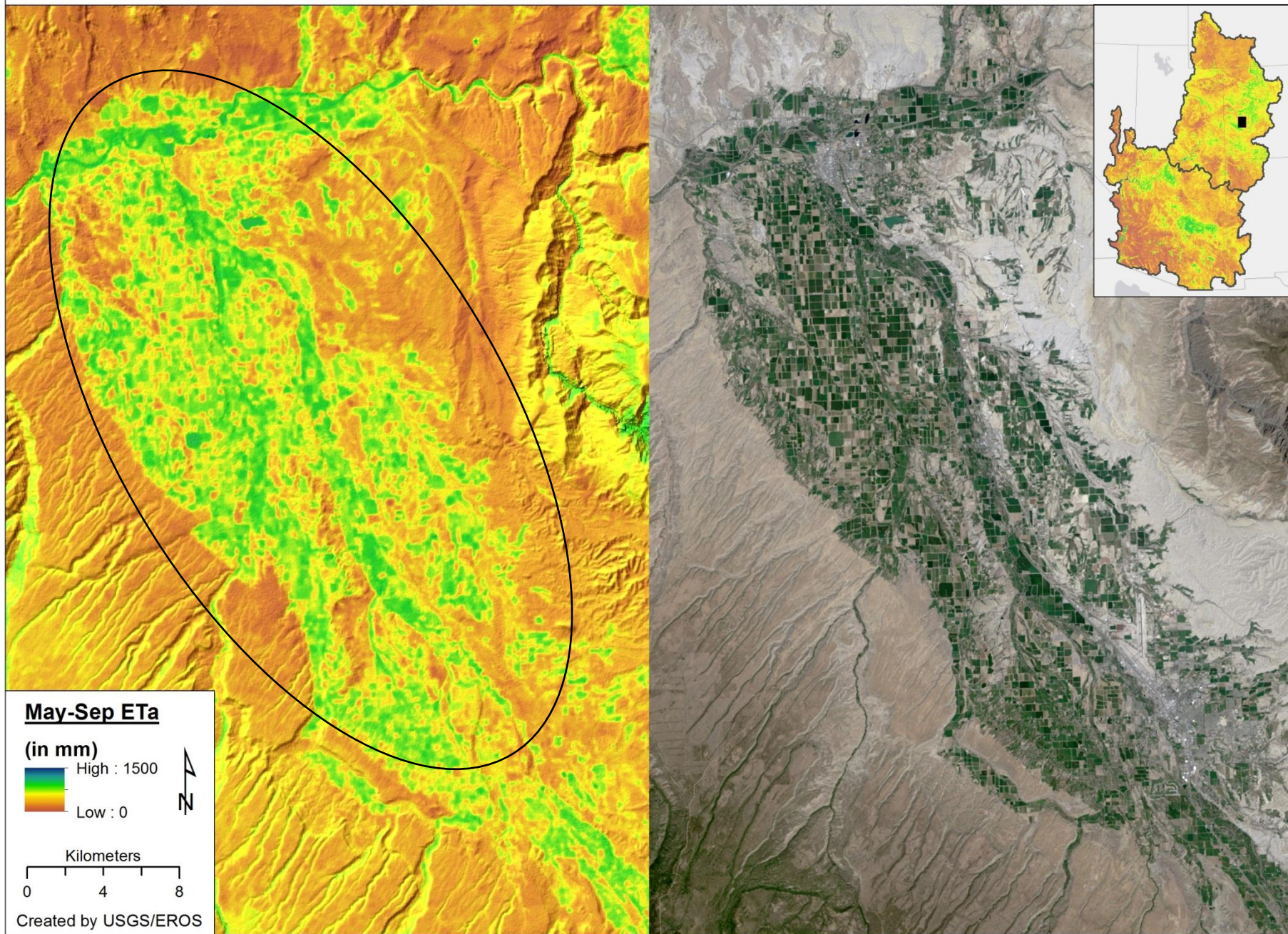
MODIS ET



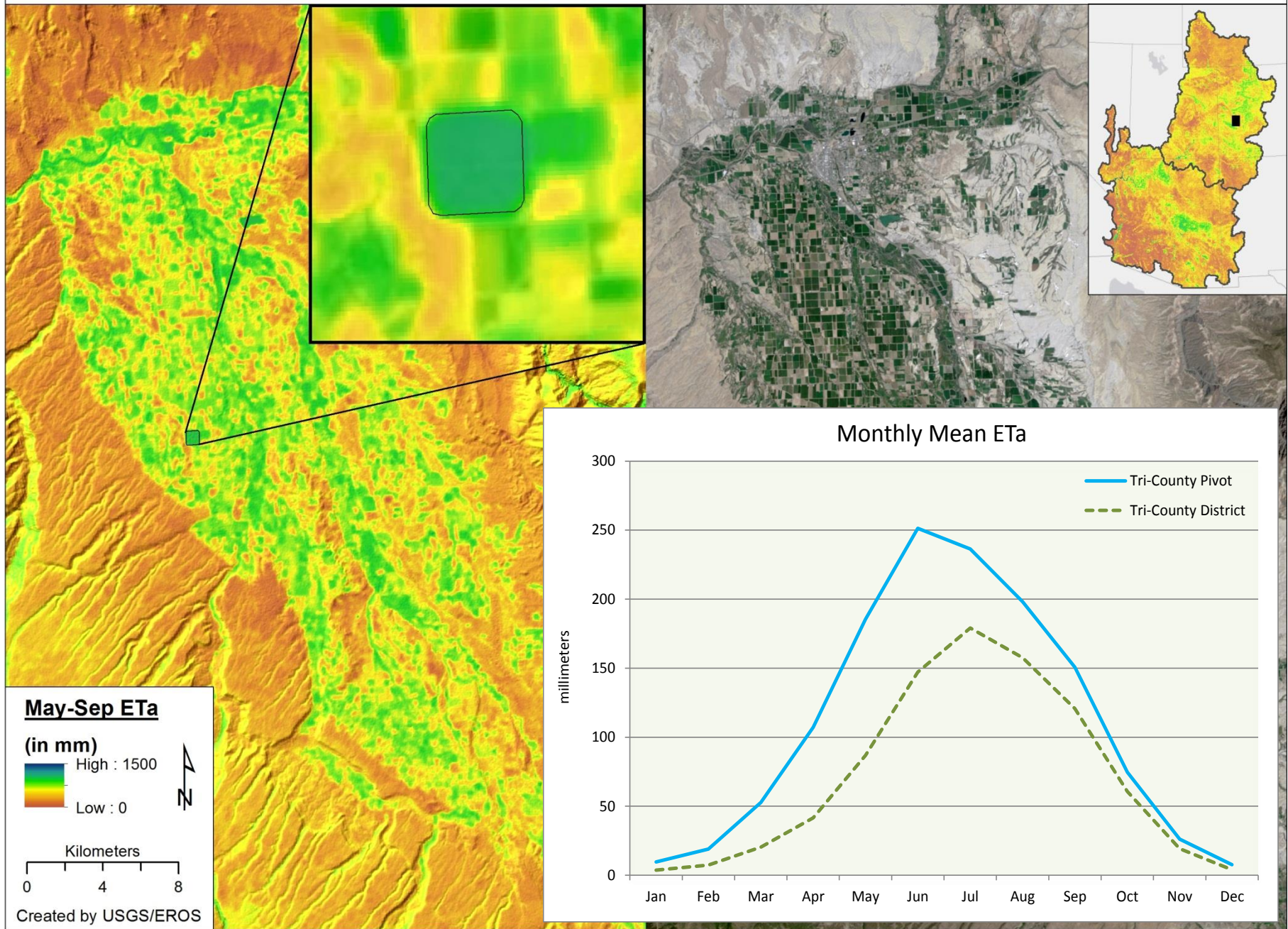
Landsat ET



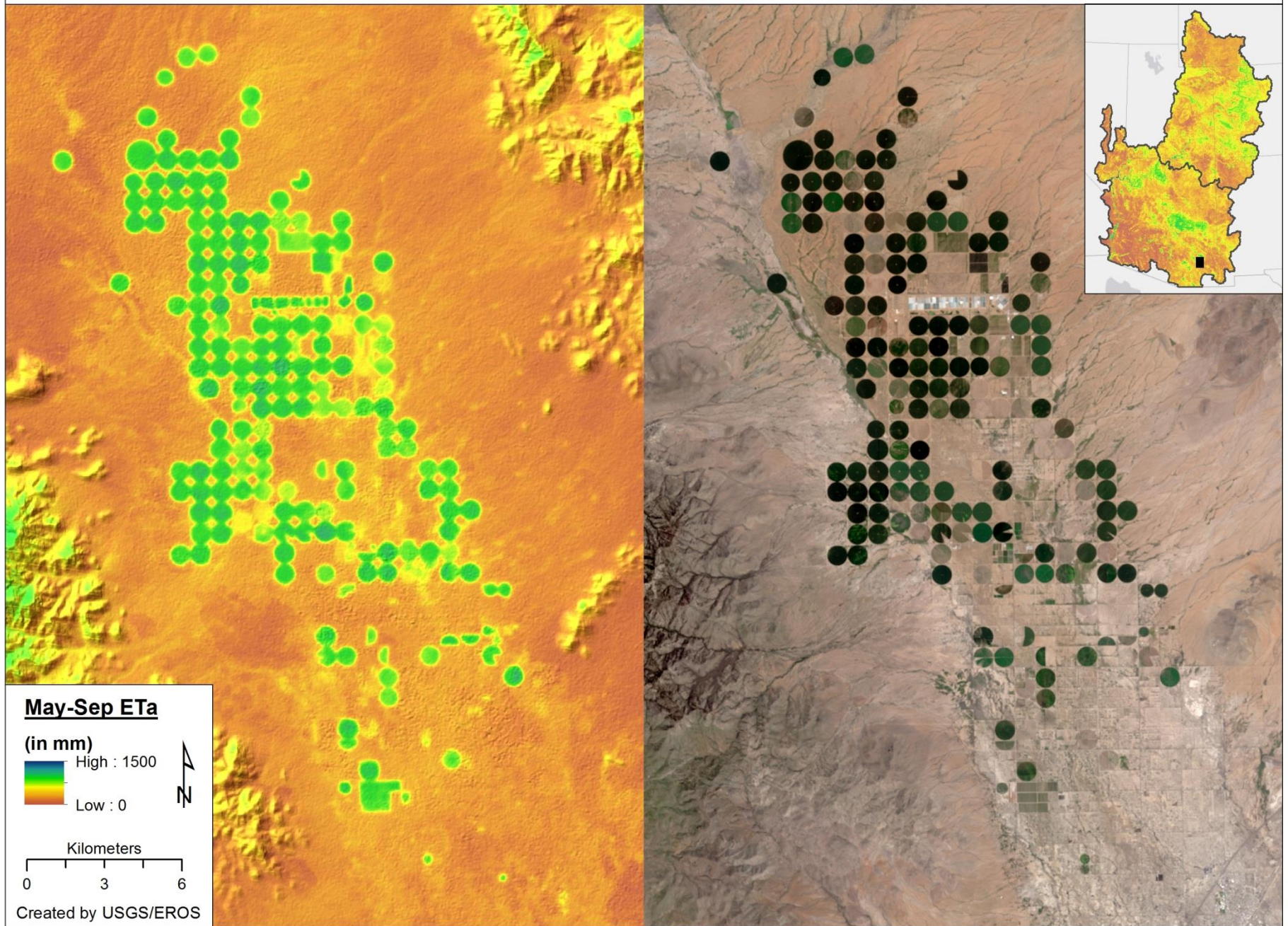
Tri-County Water Conservancy District - 2013 - Landsat 8



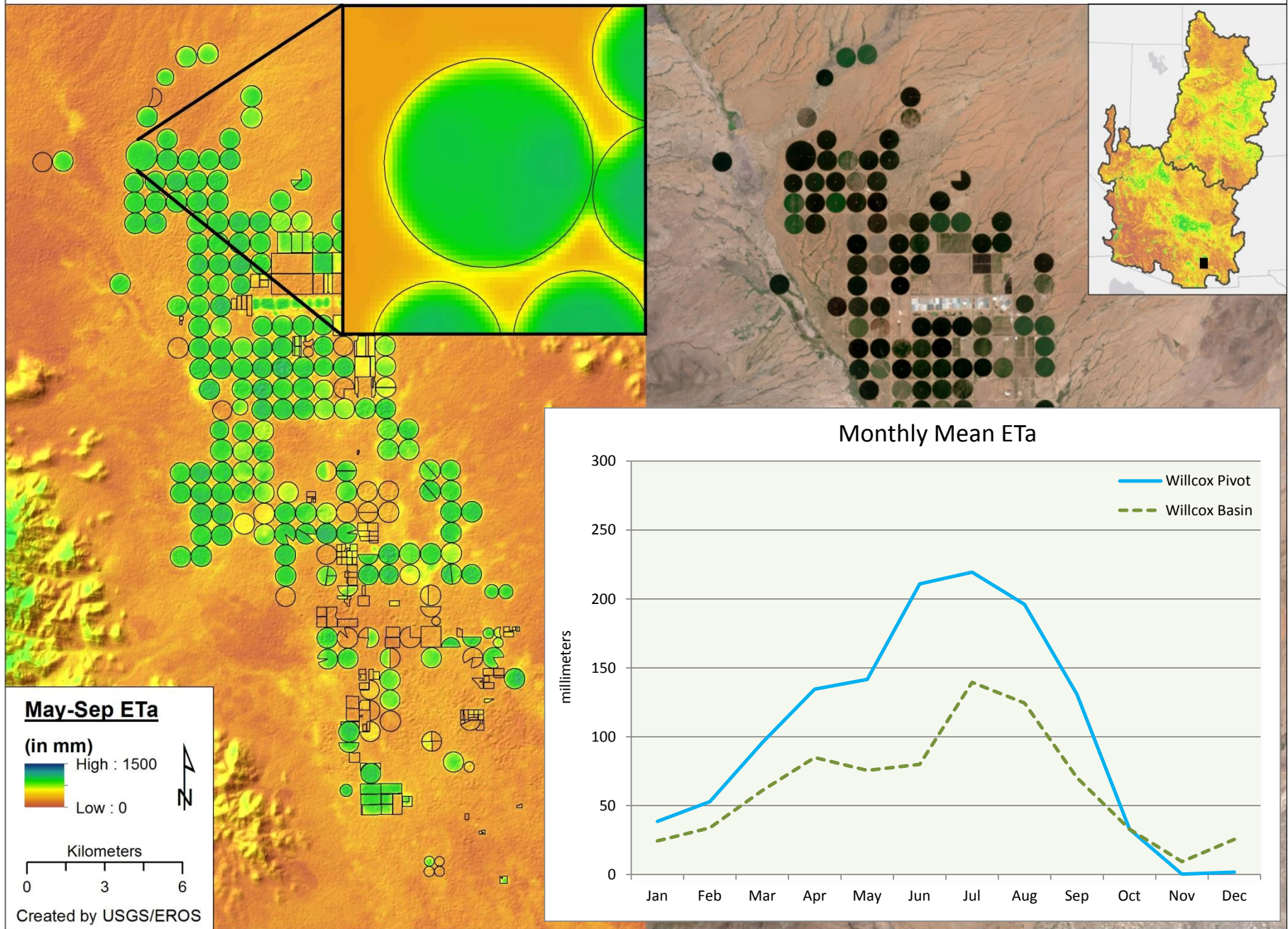
Tri-County Water Conservancy District - 2013 - Landsat 8



Willcox Basin Irrigation - 2013 - Landsat 8



Willcox Basin Irrigation - 2013 - Landsat 8



Conclusion

Remote sensing and hydrologic modeling can provide globally consistent and locally relevant data and information.

- 1) We can monitor landscape response anomalies every 1 Km², every dekad--globally
 - for drought early warning
- 2) We can map and quantify crop water use volumes
 - for planning and designing irrigation systems
- 3) Careful groundtruthing of remote sensing ET is necessary to remove bias before use in volumetric calculations



Thank you

